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Life history patterns and population fluctuations of snow crab (*Chionoecetes opilio*) in the fjord of Bonne Bay on the west coast of Newfoundland, Canada - from 1983 to 1990.

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ABSTRACT

The Bonne Bay snow crab (*Chionoecetes opilio*) population has been studied since 1983 for environmental and intrapopulational effects on growth, recruitment and terminal molt. Wide fluctuations in modal size group relative abundance are attributed to large year to year variation in recruitment and a short life span (3 to 4 years) beyond the terminal molt. A wide size range among morphometrically mature individuals results from individuals within the same cohort reaching morphometric maturity over several years rather than from cohorts maturing at different times. Hatching of the brood, mating and spawning all occur in strong synchrony among multiparous females. The external timing factor appears to be the spring phytoplankton bloom which takes place after the ice break. The rain of particulate organic matter from the spring plankton bloom may provide the stimulus to release larvae and initiate the mating behavior. Synchronizing the release of larvae into the plankton with the peak abundance of food may reduce fluctuations in recruitment. We suggest that the strong fluctuations observed in the abundance of early benthic stages result from year to year fluctuations in summer suprathermoclinal hydrological conditions rather than from match/mismatch of the occurrence of larvae with the spring bloom.

RÉSUMÉ

Depuis 1983, les effets environnementaux et intra-spécifiques de la population sur la croissance, le recrutement et de la mue terminale ont été étudiés sur la population de crabe des neiges (*Chionoecetes opilio*) de Bonne Bay. Les fluctuations importantes de l'abondance relative des groupes de taille modale sont attribuées à de grandes fluctuations annuelles du recrutement et une courte durée de vie (3 à 4 ans) après la mue terminale. La grande étendue de taille chez les individus morphométriquement matures résulte du fait que les individus d'une même cohorte atteignent la maturité morphométrique sur plusieurs années, plutôt que de la participation de plusieures cohortes chacune ayant interrompu sa croissance à un âge spécifique par rapport au temps. L'éclosion des oeufs, l'accouplement et la ponte des femelles multipares sont fortement synchronisés. Le facteur externe qui synchronise ces phénomènes semble être la floraison du phytoplancton qui survient après le bris de la glace. La matière organique non-utilisée et les pelotes fécales tombent au fond, signalant ainsi le moment opportun pour l'éclosion des oeufs et le comportement d'accouplement. Le synchronisme de l'éclosion des oeufs avec l'abondance optimale de nourriture lors de la floraison phytoplanctonique diminuerait les risques de fluctuation du recrutement. Il est suggéré que les fortes fluctuations observées au niveau de l'abondance des premiers stades benthiques résultent des fluctuations annuelles des conditions hydrologiques suprathermoclinales estivales plutôt que d'un effet passif de "simultanéité/absence de simultanéité" de la présence des larves lors de la floraison printanière.

INTRODUCTION

Benthic stages of snow crab (*Chionoecetes opilio*) resident in Bonne Bay, Newfoundland (Fig. 1), are isolated from the rest of the Gulf of St Lawrence by a 50 m deep sill at the entrance of the fjord. This isolated population is found within two inland basins at depth of 120 and 200 m , which are easily accessible from shore. Long term population studies of snow crab are therefore facilitated at this study site for a species which is usually found at 20 km or more from the coast.

The reproductive behavior of snow crab has been studied in Bonne Bay since 1982 (Taylor *et al.* 1985, Hooper 1986, Conan and Comeau 1986, Ennis *et al.* 1988 a,b, 1989, 1990, Comeau *et al.* 1989). The information was obtained mainly from diving observations of specimens collected between 15 and 55 m water depth during the short seasonal shallow water incursion of mating couples from May to early June. Comeau *et al.* (1989) also discussed the snow crab population structure and dynamics in Bonne Bay from 1984 to 1988. Since 1983 we have monitored all stages of the population to examine growth and the timing of reproductive events.

The objectives of the present study are to examine the factors influencing: recruitment to early benthic stages, the terminal molt to morphometric maturity as defined by Conan and Comeau (1986) in males and in females, and the synchronization of its life cycle (growth and reproduction) with the seasonal fluctuation of the environment.

MATERIAL AND METHODS

Study site

Bonne Bay consists of two fjords: the outer basin extending to South Arm and the East Arm, connected by a small shallow narrow (Fig. 1). There are very steep slopes on both sides of the fjord that extend to depths of 120 m to a flat and muddy bottom. The snow crab monitored in this study are located in the outer basin (Fig. 1).

Sampling gear

Snow crab mating couples were collected using SCUBA at depths ranging from 20 to 55 m. Samples were obtained and photographs taken from 1984 to 1990. No samples were taken in 1986. Couples were collected and placed in individual mesh bags for the analysis of allometry of mating partners.

Tangle nets were used from 1987 to 1990 to capture couples and single crabs at depths ranging from 25 to 120 m to provide information on the seasonal occurrence of couples below 55 m. Males continue to hold their mate in one of their claws even after being caught in the tangle net whereas couples are seldom found in trap or trawl catches.

Trap surveys were conducted in September 1983, May 1985, May and June 1987, April to August 1988, April to September 1989 and May to August 1990. Small Japanese type conical traps (base diameter: 115 cm, height: 62 cm, opening: 51 cm) were covered with a 20 mm mesh net. The traps were set along the depth gradient on the steep sides of the fjord to monitor the vertical distribution of the crabs in relation to the seasonal variations in the thermocline and the halocline, and to follow the egg maturation cycle of berried females.

A Bay of Biscay *Nephrops* 20 m head rope otter trawl with 2. 5 cm mesh cod end was used to quantitatively sample snow crab on the soft bottom of the fjord. The net has a heavy chain foot rope and is designed to capture crustaceans semi-buried in the mud. The bottom area covered by the trawl tows was calibrated using a "SCANMAR" net monitoring system.

Plankton samples were taken from early May to August in 1988 and from late April to September in 1989. The plankton net consisted of a 0. 5 m diameter metal ring frame, a flowmeter and a conical 500 µm mesh net with a cod end bottle. Vertical tows were taken to follow the development of snow crab larval stages and of the accompanying fauna throughout the season.

Hydrological parameters were measured every three days in 1988 and 1989. Turbidity measured with a secchi disk was used as as to indicate the occurrence of phytoplankton blooms. Water samples were taken at 10 m intervals over the whole

water column using a niskin water sampler equipped with a Vemco digital locking thermometer. From each sample: salinity was measured using a hydrometer, oxygen was measured using a portable oxygen probe and particulate organic carbon (POC) was measured using the combustion method of Strickland and Parsons (1972). Additional profiles were obtained using a CTD probe for temperature, salinity and dissolved oxygen.

Biological parameters

The following characteristics of all crabs caught were recorded: sex, carapace width (CW), absence of limbs (as an index of regeneration potential) and appearance of the carapace (white, clean, fouled by epibionts; as an index of time lapsed after molt). The appearance of the carapace was noted as 1) white-shell (carapace condition shortly after molting characterized by a soft exoskeleton and sharp spines on the chela and carapace), 2) clean-shell (hard-shell with sharp spines and no epizoites can be observed), 3) medium-shell (the carapace is clean and only *Spirorbidae* shells can be observed) and 4) old-shell (the carapace is heavily fouled by numerous epizoites such as large hydroid or bryozoan colonies and decaying *Spirorbidae* shells). Prior to the 1990 survey, and for the 1990 trap and tangle net data, the clean-shell and medium-shell categories were considered as new-shell. The claw height (CH) was measured for the males. The presence and color of a brood under the abdomen of the females (as an index of egg development stage) and presence of old and new grasping marks on the pereiopods (as an index of mating embrace) were noted for the females. All measurements were made to the nearest 0. 1 mm using calipers.

The molt stage was determined using the technique described by Moriyasu and Mallet (1986). The maxillipedes of several hundred males and females were collected from April to August during 5 consecutive years from 1985 to 1990.

Statistical methods

Morphometric maturity of males was identified using the method described by Conan and Comeau (1986). The terminology used for maturity is described in Conan, Moriyasu *et al.* (1988) as immature (< 34 mm CW), juvenile (from

approximately 34 to 120 mm CW for male with small claw) and mature (> 55 mm CW for male with big claw).

Chi square tests were used to compare the sex ratios and males in couples as a function of depth.

RESULTS

Long term changes in benthic population structure

The trap data collected from 1983 to 1990 showed an increase in small new-shell males. The mean CW of males decreased from 119.0 mm in 1983 to 79.4 mm in 1989 as shown in Table 1 and Figures 2, 3, 4, 5 and 6, followed by a slight increase to 88.3 mm in 1990 (Table 1, Fig. 7). The primary mode observed at approximately 120 mm CW in 1983 (Fig. 2) was not evident and there were two modes at 74 mm and 100 mm CW in 1989 and 1990 (Figs 6 and 7). The percentage of new-shell male increased from 10.6% to 91.2% between 1987 and 1988 (Table 1). The modes observed at approximately 74 mm CW in 1989 (Fig. 6) and 100 mm CW in 1990 (Fig. 7) were predominantly new-shell males. Trap data showed a decrease in the recruitment of small male crab from 1988 to 1990, as the 1990 mode at 74 mm CW is predominantly small mature male crabs with old-shell (Fig. 7B and C) compared with 1988 and 1989 (Figs 5B, C and 6C, D). The female main CW mode remained constant at 70 mm (Table 1, Figs 8, 9, 10, 11 and 12).

The tangle net data showed a change toward small new-shell males. The tangle net data showed that the male mean CW decreased from 110.8 mm in 1987 to 80.2 mm in 1988 and then increased steadily to 93.5 mm in 1990 (Table 1, Figs 13, 14, 15 and 16). The tangle net data also showed that the mode at 120 mm CW in 1987 was completely absent in 1989 and 1990 (Figs. 13, 15 and 16) and new-shell crab were predominantly observed at the 100 mm CW mode in 1990 (Fig. 16C). The female main CW mode remained constant at approximately 67 mm (Table 1, Figs 17 and 18).

Trawl data showed the growth of the juvenile component of the population and the increase of the male mature group as juvenile crab reached morphometric maturity. A total of 2044, 342, 762 and 1354 males were caught by trawling in

1985 (July, August and October), 1988 (July), 1989 (July) and 1990 (June and July) respectively. The size frequency distributions of the immature and juvenile males ranged from 14.1 to 59.0 mm CW with three modes at 22 mm, 31 mm and 44 mm in 1985 (Fig. 19A), and from 27.3 mm to 103.2 mm, with modes around 60 mm and 80 mm, in 1988 (Fig. 19B). In 1989, the size ranged from 28.4 mm to 105.0 mm with a major mode around 78 mm and two minor modes around 63 mm and 98 mm (Fig. 19C) and from 22.8 mm to 116.6 mm with major modes around 80 mm and 100 mm in 1990 (Fig. 19D and 20). There were few differences between the incidence of white crab or clean shell animals among immature and juvenile (Table 1). An increase of the mature group was observed from 1985 to 1990 (Fig. 21). The range of the sizes for mature males was from 51.0 mm to 132.3 mm from 1985 to 1990. The number of crab larger than 120 mm decreased from 1985 to 1988 (Figs 22A and 22B) while the modal class size increased at 60 mm, 75 mm and 100 mm from 1988 to 1990 (Figs 22B, C, D, 23 and 24). A slight increase in the number of males larger than 120 mm was observed in 1990 (Figs 22D and 24).

Trawl data showed a change in the size composition of the female population between 1985 and 1990. A total of 3049, 275, 775 and 1484 females were caught in 1985, 1988, 1989 and 1990 respectively (Table 1, Figs 25 and 26). Modes were observed at 22 mm, 30 mm, 44 mm and 70 mm CW in 1985 (Figs 25A and 26A). Females within the size class 55 mm CW were immature (82.0%, Fig. 25A) and all females larger than 55 mm CW (17.1%) were old-shell multiparous females with orange eggs (Table 2 and Fig. 26A). Two modes, one around 55 mm CW and the another at 67 mm CW, were observed in 1988 (Figs 25B and 26B) and one major mode was observed at 66.0 mm CW in 1989 (Fig. 26C) and 1990 (Fig. 26D). The percentage of immature females decreased from 82.9% in 1985 to 2.1% in 1990 (Figs 25 and 26).

Discriminant function and sex ratios

A discriminant function was calculated from the 1989 (Fig. 21C) trawl survey data. The analysis forecasts that 99% of the observations will be correctly assigned to either groups (juvenile-immature male or morphometrically mature male) when the discriminant function:

$$Y = 0.6083296 \ln CH - 0.79368449 \ln CW + 1.7889209$$

is used. If $Y < 0$, the individual is assigned to the juvenile category; if $Y > 0$ the individual is assigned to the morphometrically mature category. Alternatively, if ln CH is plotted as a function of ln CW all points above the line calculated from the function:

$$\ln CH = -2.9407 + 1.30469 \ln CW$$

will be identified as morphometrically mature males. This discriminant function was used to identify morphometric maturity in this report.

Significant ($p < 0,001$) changes in the sex ratios of large males (> 90 mm CW) and mature females were observed from 1985 to 1990. The calculated sex ratios (male:female) dropped from 1:9.5 in 1985 to 1:3.6 in 1988 and 1989, and to 1:1.9 in 1990. No significant ($p > 0,05$) changes were observed in the sex ratios of total males : total females from 1985 to 1990 (1:1).

Changes in oceanographic parameters

The temperature profiles taken in early spring of 1989 and 1990 showed a very homogeneous water mass. A thermocline at 40 to 50 m formed gradually from April to July in 1989 (Fig. 27). In 1990, the surface temperature increased from May 9 to May 18 (Fig. 28 A - E) and then became well mixed from top to bottom on May 22 (Fig. 28 F). The formation of a thermocline resumed on May 25 and a well defined thermocline formed at 40 to 60 m during the summer (Fig. 28 G - R). Water temperatures below 80 m for both years remained very stable between -1.5° C and 0 ° C throughout the sampling season.

The salinity profiles (Figs 29 and 30) showed that water was well mixed and stable at the beginning of the sampling season around 33 ppt in 1989 and 32 ppt in 1990. The formation of a shallow water halocline around 10 m was detected at the beginning of each sampling season. The halocline varied during the season with surface salinities ranging from 22 ppt to 31 ppt Towards the end of the season, salinity gradually increased from 28 ppt at the surface to 33.5 ppt on the bottom. A homogeneous salinity profile was observed on May 22, 1990 (Fig. 30 F).

There was a spring seasonal decrease in water visibility to a low of 4.5 m by the first week of May in all years (1988-1990) followed by an increase through the season (Figs 31, 32 and 33). The greenish color of the water from the spring phytoplankton bloom coincided with the lowest visibility measurement in early May. Less intense blooms were observed during the summer.

The data from the POC profiles were used to estimate an average sinking rate for POC of 11 m per day (Fig. 34). Immediately after the breaking of the ice, the POC was homogeneous in the water column with values between 3 mg/l and 4 mg/l. From April 22 to April 28, the POC increased to values of 5.5 mg/l at the surface and decreased from 10 to 120 m. The POC pulse sank to 20 m by May 2 and to depths ranging from 90 to 120 m by May 10. Other pulses were observed on May 29, June 7, June 26 and July 15. The POC later stabilized throughout the water column and reached high values of 4 to 11 mg/l by September 5.

Timing of molt events

Mature males and females collected from April to August were exclusively in intermolt stage C_4. In 1986, a few exuviae were found while diving at 30 m in early April. In 1989 and 1990, a large number of exuviae were collected in May (Fig. 35) but few recently molted crabs could be found in the vicinity. Almost all exuviae were attributed to juvenile animals using the discriminant function (Fig. 36).

Timing of reproductive events

Pairs of males and females in precopulating embrace were observed while diving from mid April to mid June from 1984 to 1990 (Table 3). Data from tangle nets showed that couples could be found from the shallowest to the deepest part of the fjord (120 m). The mean CW of mating couples and the percentage of old carapace crab decreased from 1984 to 1988 (Table 3, Figs 37, 38, 41 and 42), while an opposite trend was observed from 1988 to 1990. The percentage of old carapace crab fluctuated slightly for males and drastically for females from 1989 to 1990 (Table 3, Figs 39, 40, 43 and 44). At the same time, the percentage of males under 95 mm CW increased from 0% in 1984 to a high of 77.9% in 1988 and decreased to 25.8 % in 1990 (Table 3). The number of primiparous females

observed in mating couples was low in 1988 (5) and 1989 (7). No primiparous females were observed mating in 1990.

Mating couples caught in 1984, 1985 and 1987 were composed of large (>95 mm CW) old-shell males, many with missing limbs, and mating with large old-shell females in similar condition (Figs 45 A, B and C). In 1988, two distinct groups of mating couples were observed (Fig 45 D). Couples were composed of: large old-carapace males mating with large old-shell females and small males with clean carapaces, mating with smaller clean shell females. The two types of males segregated into different groups with little intermixing. Couples caught deeper than 50 m were mostly "dirty" crab (82%) compared to the cleaner ones caught at depths less than 50 m (50%). The carapace condition of paired males, caught at depths greater than 50 m (below the thermocline) was significantly different ($p < 0.05$) from the carapace condition of paired males caught at depths above 50 m. White-shell males were never observed in couples. The 1989 and 1990 mating couples data showed a more homogeneous distribution of size ratios (Figs 45 E and F).

Eggs hatched during the precopulatory embrace and on 5 occasions during scuba diving pairs were observed copulating. All males observed (> 97%) were morphometrically mature (Fig. 46). All females encountered in pairs in May and June carried well developed (black) eggs or had recently spawned as observed from the bright orange color of the eggs. The transition from old (black) to recently spawned eggs takes approximately one week.. Most females carried old grasping marks indicating mating over several mating seasons prior to the present. Among those which did not bear grasping marks, two had their carapaces dated using radioelements and were shown to have molted one year earlier. Clean carapace females bearing bright orange eggs could be found before any mating pairs were observed in traps or tangle net samples.

Vertical distribution of benthic stages

Diving observations combined with trap and tangle net data from the vertical gradient of the slope of the southern fjord cliff provided information on the upper limit of the distribution of the crabs throughout the season. Prior to mid-April, crabs were dispersed over all depths. Exuviae found in shallow water at the time of the first sampling in 1989 and 1990 (Fig. 35) confirmed this. As the season proceeded,

the upper limit of the crab vertical distribution deepened from 15 m to 50 m by late May to mid June as the 3°C thermal isoline deepened.

Occurrence of larval stages in the plankton

The presence and abundance of *Chionoecetes opilio*, *Hyas spp* and *Cancer irroratus* larvae collected in the plankton samples from April to September 1989 are presented in Table 4. The larvae of the three species appear over successive and overlapping seasonal time ranges. *C. opilio* larvae were observed earlier followed by *Hyas spp.* and *C irroratus*, which were observed in July. The complete series of larval stages up to megalope were observed for *Hyas spp* and *C. irroratus.* Only zoe 1 stage were found for *C. opilio.*

Catch per unit effort

The catch per unit effort (CPUE) calculated from trawl surveys showed that the population of male crab as a whole experienced small fluctuations from 1985 to 1990 as CPUE decreased from 85 crab/tow in 1985 to 68 crab/tow in 1988 and then remained at 70 crab/tow from 1988 to 1990 (Table 5). The population of female crab showed the same fluctuations with a CPUE at 77 crab/tow in 1990 (Table 5). Trap, more selective toward the large hard shell morphometrically mature male and female, showed a decrease in the CPUE from 53.33 crab/trap haul in 1985 to 5.62 crab/trap haul in 1987 and then a slow increase to 30.49 crab/trap haul in 1990 (Table 5).

DISCUSSION

Comparison of the mating couples from 1984 to 1990 showed that different types of males participated in the reproduction in different years. From 1984 to 1987, large males with old carapace's, that originated from a very mature and old cohort of the population, were observed in couples. In 1988 and 1989, the males were predominantly small with a clean carapace which indicated that they were from a more recent cohort. In 1990, males were larger but still had clean carapace.

The observations on size distributions of mating couples in Bonne Bay are similar to Ennis *et al.* (1988a, b, 1989 and 1990). However, Ennis *et al.* (1989,

1990) observed in 1988 that 80% of clean carapace for both males and females, compared to our estimates of 34.9% for males and 52.3% for females in 1988, as shown in Table 3. These differences may be due to the different sampling methods used as Ennis *et al.* (1989, 1990) collected data by diving at depths ranging from 10 to 30 m, whereas data presented in this report are from diving and tangle net which captured couples in all depths of water (down to 120 m).

Observations on the carapace condition of males and the oceanography in Bonne Bay indicates a segregation of the couples on the very steep slope. Inferior males, either old "amputees" or clean and small males, tend to concentrate in shallow waters at the limits of the thermocline once it stabilized at 50 m, while dominant (large and hard shell) males occupied the environment at greater depths where most of the snow crab population normally reside. Experiments using sonic tags also showed a strong sedentary behavior for large old carapace males and active movements for small clean carapace males (Maynard, unpubl. data).

We believe that the vertical movement of couples is not due to a breeding migration towards shallow water, as stated by Hooper (1986), but a competitive territorial exclusion of inferior males by dominant males. The movement of couples up the slope observed in Bonne Bay is not directly related to mating, as premolting juvenile crabs also move up to shallow water to molt, but is a combination of competitive exclusion (during mating) of dominant males towards inferior males forcing the inferior males to less favorable grounds, the search for refuge against cannibalism (during molting) and the bathymetry of the bay, which limits the horizontal movement of inferior males.

Males in couples encountered in Bonne Bay since 1985 were all identified as morphometrically mature. Conan and Comeau (1986) observed that among morphometrically mature animals, only the largest ones (approximately 95 mm CW and more) were functionally mature, i.e. would grab a female, carry her around (precopulatory embrace) and mate. Data from the present study support this as well as the statements by Ennis *et al.* (1988a, b and 1989) and Comeau *et al.* (1989) who showed that size (<95 mm CW) did not prevent males from mating. In populations with a sufficient number of large males, males < 95 mm CW are excluded from mating. When a cohort initially reaches maturity at small sizes in the absence of old larger morphometrically mature males, the newly mature small

males and females will successfully mate. A low number of small morphometrically mature male are normally found on the fishing grounds (Chiasson *et al.* CAFSAC 91/in prep.).

The discriminant function identified that the mature component of the population was composed of morphometrically mature males mating with mature females as found previously by Conan and Comeau (1986), Conan, Comeau *et al.* (1988) and Ennis *et al.* (1989).

Successful mating and copulation involving juvenile males or white crab males with mature females in the wild is inconclusive based on the data presented in this report. The absence of juvenile males or white crab males in couples may be explained by the timing of molting and mating. Molting of juvenile males occurs, generally, prior to the mating period (Moriyasu *et al.* 1987, Conan, Moriyasu *et al.* 1988, and our observations of juvenile exuviae), implying that only mature males which have reached terminal molt at least one year earlier are not affected by post-molting soft shell condition. During the mating period, the juvenile males and the newly mature males cannot compete with the terminal molt males for females and are excluded from mating with multiparous female due to their soft shell condition. Moriyasu and Conan (1988) reported mating of juvenile males with primiparous females in the laboratory. This was observed a month before morphometrically mature males mated with multiparous females in the wild. The presence of a large number of primiparous females having recently molted and bearing orange (recently spawned) eggs at the very beginning of the mating season of morphometrically mature couples in Bonne Bay, may indicate that primiparous females mate earlier in nature using a different mating strategy.

It is not clear yet what factors initiate mating activity in Bonne Bay. The temperature and salinity data showed no changes on the bottom (120 m) prior to the first appearance of couples on the slope. These observations were also noted in 1988 (Comeau *et al.* 1989). In 1988, the first couple caught at depth of 40 m was caught four days (May 6) after the phytoplankton bloom on May 2, 1988 (Comeau *et al.* 1989). The couples were seen moving up into shallow water immediately after the spring phytoplankton bloom. This behavior is presently being studied while monitoring environmental parameters. The 1989 oceanographic data showed that the POC, resulting from a bloom, reached depths of 120 m within 10

days and appears to coincide with mating activity of morphometrically mature individuals as the first couple was observed at 50 m five days after the pulse of POC had reached the bottom by May 10, 1989 (Fig. 34).

Interpretations of snow crab population structure should be based on trawl data rather than trap data as the percentage of juvenile males captured by traps was low (5.2% for CW > 55 mm) compared to trawling where 70% of the males >55 mm CW were identified as juveniles. A Nephrops trawl has been used by several authors (Comeau 1985, Conan and Comeau 1986, Comeau 1987, Mallet *et al.* 1988 and 1989) to study snow crab populations as it is less selective towards mature and hard shell crab than traps. Our data indicates that hard shell morphometrically mature crabs which have reached terminal molt are more prone to be caught in traps than other categories. It is the percentage of crabs reaching morphometric maturity as a function of size which now appears to be determinant for yield predictions. So far, no observations are available on the determinism of terminal molt at size due to selective depletion of morphometrically mature crabs by heavy trap fishing in the Gulf of St. Lawrence. By following the growth of cohorts through time in Bonne Bay such information should be provided.

The growth increments based on the histograms from the 1985 (Fig. 19A) trawl survey are 40.9% (22 mm to 31 mm CW) and 41.9% (31 mm to 44 mm CW). These increments are approximately 10% higher than laboratory data on carapace width increments found by Miller and Watson (1976) for small crabs from the Gulf of St. Lawrence. Furthermore, carapace ageing using a radioelement technique indicates that the inter-molt period (time between molt) for small males in the 30 and 40 mm CW group is approximately one year (Conan *et al.* unpublished data). It may be assumed, as a first approximation, that each mode represents a cohort with molting occurring once a year.

The growth at molt of juvenile and mature males should be analyzed separately for the 1988, 1989 and 1990 trawl data due to a difference in growth rate of juvenile males at the terminal molt (Moriyasu *et al.* 1987, aquarium data). Data on juvenile males in 1985 (Fig. 19A), showed an absence of recently recruited cohorts. Data over the same size ranges in 1988, 1989 and 1990 (Fig. 19B, 19C and 19D) showed the presence of well represented cohorts over the whole range of sizes. Morphometrically mature males in 1988, 1989 and 1990

(Figs 22B, 22C, 22D, 23 and 24) were composed of clean carapace individuals with smaller CW compared to 1985 (Fig. 22A) old carapace, indicating recent growth into the morphometrically mature category from the juvenile males category. The growth to morphometric maturity and subsequent increased trapability is expected to last over several years and up to sizes greater than 120 mm CW.

The percentage of growth from the mode at 44 mm CW (Fig. 19A) to the mode at 60 mm CW (Fig. 19B) was approximately 36.4%. The growth rate to the next mode was approximately 33.3% (from 60 mm to 80 mm CW) and 25% (from 80 mm to 100 mm CW). The molt to maturity was partially achieved from modes at approximately 60 mm CW and 80 mm CW. The percentage of CW increase for the individuals molting to maturity was 23.3% (60 mm molting to 74 mm CW) and 25% (80 mm molting to 100 mm CW). Percentage of CW increments was less for the molt to maturity as anticipated from the aquarium data of Moriyasu *et al.* (1987). These findings on the molt to maturity agree with those of Moriyasu *et al.* (1987).

Results from diving, tangle net, trap and trawl surveys showed changes in the composition of the Bonne Bay snow crab population since 1983. Changes were reported by Ennis *et al.* (1988a, b and 1989), who attributed the decrease in abundance of large commercial size (> 95 mm CW) males to the rapid development of an "illegal" fishery after 1984 (Ennis *et al.* 1988a), as it was assumed that prior to 1985 the snow crab population in Bonne Bay was virgin (Taylor *et al.* 1985). However, our information from local fishermen indicated that there has always been a local, if not official, snow crab fishery in Bonne Bay. Recruitment failure over certain years, as demonstrated by our trawl data, played an important role in the fluctuations of the Bonne Bay snow crab population. Fluctuations in sex ratio do not indicate that fishing activities based on large males and not on females have substantially affected the population.

Fluctuations in abundance of large terminal molt males in Bonne Bay can be explained from the absence of cohorts observed in the 1985 trawl data. Data since 1985, particularly the 1988, 1989 and 1990 trawl surveys showed changes in the population structure. The overall size ranges varied slightly from 1985 (14 mm to 132 mm CW) to 1990 (22 mm to 131 mm CW), but the relative importance of modal groups along those size ranges varied considerably. Three major modes (cohorts) observed in 1985 (Fig. 19A) were practically absent from 1988 to 1990 trawl survey

data (Fig. 19B, 19C and 19D). Only a few crab were observed at 30 mm CW in 1988 and within the 40 mm CW group in 1989 and 1990. High percentages of crabs were found at sizes > 50 mm CW from 1988 to 1990. These shifts in the population structure are due to the recruitment failure of certain year classes. An incidence of recruitment failure was indicated by a lack of males > 50 mm CW in 1985. Growth of individuals in the three major modes < 50 mm CW (recruitment pulses) in 1985 contributed to the large number of crabs > 50 mm CW observed from 1988 to 1990 and should persist for several years. Nevertheless, very few modes < 50 mm CW were observed from 1988 to 1990, indicating another recruitment failure to benthic stages over these year classes.

The recruitment failures observed in Bonne Bay seems to take place at the larval stage. Zoe 1 larvae occurred in large numbers in May and early June in 1988 and 1989. The transition from zoe 1 to zoe 2 in June, as observed by Lanteigne (1985) in the Baie des Chaleurs, was never observed in Bonne Bay. The zoe 2 and the megalope stages were not present in the samples from June, July, August and September and suggested that the high mortality at the larval stage may have been caused by warm water temperatures during the summer of 1988 and 1989 or a net outflux (flushing) of larvae from the bay, during zoe 1 stage.

Natural mortality after the molt to maturity plays an important role in the fluctuations in abundance of large terminal molt males. The ageing of carapaces by radioelement dating showed a maximum carapace age for mature males and females of approximately 4 years (Conan *et al.*, unpublished data). At this age, the carapace is fairly decalcified by bacterial or fungal action and limbs are missing (non-regenerated after the terminal molt). The indication is that most of the larger old shell males in terminal molt captured in 1985 would have died prior to 1988. This natural mortality coupled with a lack of growth into the terminal molt male group in 1985 and 1986 would explain the low number of large males observed in mating pairs and trap samples.

Changes in the Bonne Bay snow crab population structure based on data collected since 1985 can be described as follows: In 1985, the population structure was composed of small immature and juvenile males and large old-shell males in terminal molt. The immature and juvenile males are the component of the population that will molt once a year. Males in the 22 mm CW mode grew to 31 mm

CW (40.9% CW increase) in 1986, to 44 mm CW (41.9% CW increase) in 1987, and to 60 mm CW (36.4% CW increase) in 1988. Males in the 31 mm CW mode and the 44 mm CW mode reached the 60 mm CW mode in 1987 and 1986, respectively. The growth mentioned above are from juvenile crabs molting to the next juvenile size group. No molt to maturity would have been observed until 1987, which meant a considerable reduction in the abundance of large old-shell crabs by natural mortality (for terminal molt males reaching 3 years of age). The net reduction in terminal molt male crab was due to recruitment failure of the cohorts preceding the 1980's cohorts (modes observed at 22 mm, 31 mm and 44 mm CW in 1985) and mortality among mature males. The population structure became more complicated as a portion of juvenile males grew to maturity starting in 1987 from the 44 mm CW mode observed in 1985 (Fig. 19A). A portion of the males at the 60 mm CW mode (1986) grew to another juvenile size group at 80 mm CW (33.3% CW increase) and the other portion grew to maturity at 74 mm CW (23.3% CW increase). Thus, the first growth into the terminal molt male group in 1987 was composed of small (74 mm CW) males. In 1988, another growth into the terminal molt group came from the 1987 mode at 60 mm CW that grew to the 74 mm CW mode (Fig. 22B) and the 1987 mode at 80 mm CW that grew to the 100 mm CW mode (25% CW increase; Fig. 22B). It appears that the 1987 mode at 60 mm CW grew partially to the juvenile mode at 80 mm CW and to terminal molt mode at 74 mm CW in 1988 (Figs 19B and 22B). The males of the 1987 mode at 80 mm CW grew almost entirely to the terminal molt mode at 100 mm CW in 1988 (Figs 19B and 22B). The 1988 mode at 80 mm CW (Fig. 19B) grew almost entirely to the terminal molt mode at 100 mm CW in 1989 (Fig. 22C). Only a few juvenile crab can be observed at sizes around 100 mm CW in 1989 (Fig. 19C). The majority of the juvenile male at the 60 mm CW mode in 1988 (Fig. 19B) had grown to another juvenile mode at 80 mm CW (Fig. 19C) instead of molting to maturity into the 74 mm CW mature mode in 1989 (Fig. 22C). Juvenile males of the 1989 mode at 80 mm CW (Fig. 19C) grew to another juvenile mode at approximately 100 mm CW (Fig. 19D). The presence of a mode at 80 mm CW in 1990 (Fig. 19D) is due to the presence of premolt males in the sampling. Molting to maturity in 1990 was minimal as the modes representing mature males from 1989 (Fig. 22C) to 1990 (Fig. 22D) did not changed. The mode located at approximately 100 mm CW for the juvenile (Fig. 19D) increased in size. The molt to maturity may be density-dependent. The low number of terminal molt males between 1985 and 1987 may have triggered the occurrence of successful molts to maturity. Molt to morphometric

maturity for a given age group does not seem to be genetically determined. It appears that in the presence of a large number of terminal molt males, recent juvenile molters continue to grow or are eliminated, perhaps cannibalism, after the molt.

Based on these observations, the following population structure should be observed in the future: The juvenile male mode at 100 mm CW in 1990 (Fig. 19D) will grow to approximately 125 mm CW (terminal molt group) in 1991, as per the mode observed in 1985 (Fig. 22A). Some males may remain juvenile up to a carapace size of 120 mm CW and will molt to maturity at carapace sizes greater than 135 mm CW in 1992. The increase in the occurrence of large males in the mating couples and trap samples which started in 1990 should continue in 1991 due to the arrival of a large number of terminal molt males (> 120 mm CW) into the population and the death of the first small terminal molt male mode (74 mm CW) from 1987. The following year (1992), this pattern should repeat itself as the males that grew to maturity (79 mm CW and 100 mm CW) in 1988 will die, and the last molt into the large terminal molt male group (> 120 mm CW) will enter into the population. The abundance of small mature old-shell males should decrease during the following years (1993 and 1994) due to mortality. No major growth into the terminal male group is anticipated before 1995, according to Figure 19D. A recruitment failure, similar to the one observed in the years preceding the three cohorts observed in 1985 (mode 22 mm, 31 mm and 44 mm CW), should be observed. By 1993 or 1994, the population structure should be similar to the one observed in 1983-1984.

The changes in the population structure observed in Bonne Bay since 1983 can be explained by a thorough understanding of the natural history of the species. The effect of recruitment fluctuations combined with high natural mortality after reaching terminal molt stage explain most of the changes in the population structure. The observations on the the Bonne Bay snow crab population may allow us to better understand and predict fluctuations in the commercial catch for the rest of the Gulf of St Lawrence. The hypothesis of a natural 10 year life cycle is presently under study.

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REFERENCES

Comeau, M. 1985. Détermination de la maturité sexuelle par morphométrie chez le crabe des neiges *Chionoecetes opilio*. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 85/81: 15 p.

1987. Maturité gonadique et mue pré-pubérale chez le crabe des neiges, *Chionoecetes opilio* , (O. Fabricius). Thése de Maîtrise, Université de Moncton, Moncton, N.-B., 145 p.

Comeau, M., G.Y. Conan, and A. Jones. 1989. Fluctuations in mating, reproduction and recruitment of the snow crab population in Bonne Bay: Implications to fisheries management. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/79: 38 p.

Conan, G.Y., and M. Comeau. 1986. Functional maturity and terminal molt of male snow crab, *Chionoecetes opilio*. Can. J. Fish. Aquat. Sci. 43: 1710-1719.

Conan,G.Y., M. Comeau, M. Moriyasu, and R. Cormier. 1988. Reply to Donaldson and Johnson. Can J. Fish. Aquat. Sci. 45: 1501-1503.

Conan, G.Y., M. Moriyasu, M. Comeau, P. Mallet, R. Cormier, Y. Chiasson, and H. Chiasson. 1988. Growth and maturation of snow crab (*Chionoecetes opilio*). *In* Jamieson G.S., and W.D. McKone (ed.). Proceedings of the International Wokshop on Snow Crab Biology, December 8-10, 1987, Montreal, Quebec. Can. MS Rep. Fish. Aquat. Sci. 2005: 45-66.

Ennis, G. P. , R. G. Hooper, and D.M. Taylor. 1988a. Changes in size composition of male crabs (*Chionoecetes opilio*) participating in the annual breeding migration in Bonne Bay, Newfoundland. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 88/2: 14 p.

1988b. Functional maturity in small male snow crabs (*Chionoecetes opilio*). Can. J. Fish. Aquat. Sci. 45: 2106-2109.

1989. Changes in size composition of male crabs (*Chionoecetes opilio*) participating in the 1988 breeding migration in Bonne Bay. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/10: 16 p.

1990. Changes in the composition of snow crab (Chionoecetes opilio) participating in the annual breeding migration in Bonne Bay, Newfoundland. Can. J. Fish. Aquat. Sci. 47: 2242-2249.

Hooper, R. G. 1986. A spring breeding migration of the snow crab, *Chionoecetes opilio* (O. Fabr.) into shallow water in Newfoundland. Crustaceana 50: 257-264.

Lanteigne, M. 1985. Distribution spatio-temporelle des larves de crabe appartenant aux genres *Chionoecetes* et *Hyas* , dans la baie des Chaleurs, Canada. Thése de Maîtrise, Université de Moncton, Moncton, N.-B., 161 p.

Le Foll, D., E. Brichet, J.L. Reyss, C. Lalou, and D. Latrouite. 1989. Age determination of the spider crab *Maia squinado* and the European lobster *Homarus gammarus* by 228Th/228Ra chronology: possible extension to other crustaceans. Can. J. Fish. Aquat. Sci. 46: 720-724.

Mallet, P., Y. Chiasson, and M. Moriyasu. 1988. A review of catch, fishing effort and biological trends for the 1987 southwestern Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) fishery. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 88/32: 39 p.

Mallet, P., E. Wade, Y. Chiasson, P. Degrâce, G. Conan, et M. Moriyasu. 1989. La pêche du crabe des neiges (*Chionoecetes opilio*) dans le sud-ouest du golfe St. Laurent, en 1988: les prises, l'effort de pêche, l'estimation de la biomasse. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/25: 59 p.

Miller, R.J., and J. Watson. 1976. Growth per molt and limb regeneration in the spider crab, *Chionoecetes opilio* . J. Fish. Res. Board Can. 33: 1644-1649.

Moriyasu, M., and G.Y. Conan. 1988. Aquarium observation on mating behavior of snow crab, *Chionoecetes opilio* . ICES C.M. 1988/K:9.

Moriyasu, M., and P. Mallet. 1986. Molt stage of the snow crab *Chionoecetes opilio* by observation of morphogenesis of setae on the maxilla. J. Crust. Bio. 6(4): 468-490.

Moriyasu, M., G.Y. Conan, P. Mallet, Y.J. Chiasson, and H. Lacroix. 1987. Growth at molt, molting season and mating of snow crab (*Chionoecetes opilio*) in relation to functional and morphometric maturity. ICES C.M. 1987/K14, 22 p.

Strickland, J. D. H., and T. R. Parsons. 1972. A practical handbook of sea water analysis. Bull. Fish. Res. Bd. Canada. 167: 310 p.

Taylor, D.M., R.G. Hooper, and G.P. Ennis. 1985. Biological aspects of the spring breeding migration of snow crabs, *Chionoecetes opilio*, in Bonne Bay, Newfoundland (Canada). Fish. Bull. U.S. 83: 707-711.

Watson, J. 1969. Biological investigations on the spider crab Chionoecetes opilio. Can. Fish. Rep., 13: 24-47.

Table 1: Characteristics of snow crab (*C. opilio*)caught by trap, tangle net and trawl in Bonne Bay between 1983 and 1990.

Year			N	Mean CW (mm)	Range (mm)	Carapace White (%)	Carapace Clean (%)	Carapace Old (%)
Male								
Trap	1983		430	119.0	90.0 - 140.5	0	0	100.00
	1985		160	111.1	81.0 - 134.0	0	0	100.00
	1987		264	107.1	60.0 - 137.0	0	10.61	89.39
	1988		1204	89.4	52.4 - 143.8	1.30	91.24	7.46
	1989		1530	79.4	50.0 - 130.2	7.92	54.62	37.46
	1990		2134	88.3	55.4 - 131.9	0.67	52.60	46.83
Tangle net	1987		75	110.8	60.0 - 137.6	0	0.01	99.99
	1988		248	80.2	48.8 - 125.9	0	70.16	29.84
	1989		1950	88.6	43.8 - 136.2	9.83	58.13	32.05
	1990		794	93.5	51.0 - 131.4	5.36	50.57	44.07
Trawl	1985	juvenile	1967	33.8	14.1 - 59.0	0	100.00	0
		mature	77	103.2	54.0 - 132.3	0	0	100.00
		total	2044	36.4	14.1 - 132.3	0	96.23	3.77
	1988	juvenile	262	63.6	27.3 - 103.2	0	99.62	0.38
		mature	78	92.5	55.6 - 130.0	0	85.60	14.10
		total	342	70.5	27.3 - 130.0	0	96.49	3.51
	1989	juvenile	500	76.1	28.4 - 105.0	0.20	98.58	1.22
		mature	257	88.3	52.4 - 127.4	1.19	62.95	35.86
		total	762	80.3	28.4 - 127.8	0.53	86.65	12.82
	1990	juvenile	778	88.5	22.8 - 116.6	3.08	92.94	3.98
		mature	573	92.3	51.0 - 131.3	2.09	66.49	31.41
		total	1354	90.1	22.8 - 131.3	2.73	81.68	15.59
Female								
Trap	1983		132	70.0	54.9 - 85.3	0	0	100.00
	1985		154	70.1	43.0 - 85.0	0	0	100.00
	1987		51	72.0	59.0 - 83.0	0	0.76	99.24
	1988		2050	71.1	51.1 - 90.0	0	61.69	38.31
	1989		532	70.6	52.4 - 87.6	0	11.26	88.74
	1990		6	64.8	40.6 - 73.5	0	1.67	98.33
Tangle net	1987		10	72.2	65.0 - 81.4	0	0	100.00
	1988		105	67.6	48.5 - 82.8	0	88.46	11.54
	1989		605	66.8	47.7 - 88.4	5.45	83.47	11.07
	1990		46	68.1	53.2 - 82.2	0	6.67	93.33
Trawl	1985		3049	41.3	12.0 - 86.0	0	82.88	17.12
	1988		275	60.9	28.4 - 78.6	0	44.73	55.27
	1989		775	64.0	32.0 - 80.3	0	69.55	30.45
	1990		1484	65.3	19.7 - 88.4	0.27	50.34	49.39

Table 2: Egg characteristics in relation to carapace condition for female snow crab (*C. opilio*) caught by diving, trap, tangle net and trawl in Bonne Bay between 1984 and 1990.

Year	Sampling gear	N	Clean shell			Old shell		
			Bright orange	Orange	Old/hatching	Bright orange	Orange	Old/hatching
1984	Diving	28	0	0	0	1	0	27
1985	Diving	3	0	0	0	0	0	3
	Trap	154	0	0	0	0	149	4
	Trawl	522	0	0	0	0	522	0
1987	Diving	33	0	0	0	1	0	32
	Tangle net	10	0	0	0	3	0	7
	Trap	51	0	0	0	0	28	23
1988	Diving	44	2	0	34	0	0	8
	Tangle net	105	42	1	49	0	0	13
	Trap*	2050	16	871	203	16	604	53
	Trawl	205	0	52	1	0	152	0
1989	Diving	235	1	0	233	0	0	1
	Tangle net	605	23	23	455	0	16	88
	Trap **	532	2	49	9	1	364	55
	Trawl ***	758	6	467	51	1	229	4
1990	Diving	136	0	0	11	0	0	125
	Tangle net	46	0	0	4	2	4	36
	Trap	6	0	1	0	0	4	1
	Trawl	1437	14	687	3	2	715	16

* 20 females with rotten egg mass
** 52 females with rotten egg mass
*** 2 females with rotten egg mass

Table 3: Summary of snow crab (*C. opilio*) characteristics for couples caught in Bonne Bay during the 1984, 1985, 1987, 1988, 1989 and 1990 spring mating season.

Year		N	Mean CW (mm)	Range (mm)	% Clean Carapace	% < 95 mm CW (Males)
1984	Males diving	28	118.7	97.0 - 134.2	25.0	0
	Females diving	28	69.8	59.8 - 87.0	0	–
1985	Males diving	3	110.0	99.0 - 119.0	0	0
	Females diving	3	69.3	68.0 - 72.0	0	–
1987	Males diving	28	109.6	85.8 - 122.6	3.6	7.1
	Females diving	28	70.6	59.2 - 84.3	0	–
	Males tangle net	8	107.1	85.4 - 122.0	0	25.0
	Females tangle net	8	72.8	65.0 - 81.4	0	–
	Males total	36	109.1	85.4 - 122.6	2.3	9.0
	Females total	36	71.1	59.2 - 84.3	0	–
1988	Males diving	44	80.9	56.9 - 126.8	54.5	86.4
	Females diving	44	64.2	52.1 - 76.4	81.8	–
	Males tangle net	42	89.6	60.6 - 125.9	14.3	69.0
	Females tangle net	42	65.2	48.5 - 79.7	21.4	–
	Males total	86	85.2	56.9 - 126.8	34.9	77.9
	Females total	86	64.7	48.5 - 79.7	52.3	–
1989	Males diving	235	82.7	63.6 - 110.4	86.8	89.4
	Females diving	235	64.5	49.2 - 88.9	99.6	–
	Males tangle net	333	94.2	65.0 - 131.7	64.9	49.0
	Females tangle net	333	65.7	47.7 - 79.0	90.1	–
	Males total	568	89.4	63.6 -131.7	73.9	65.7
	Females total	568	65.2	47.7 - 88.9	94.0	–
1990	Males diving	136	98.6	72.1 - 128.4	69.9	27.9
	Females diving	136	65.4	50.6 - 78.6	8.1	–
	Males tangle net	23	104.5	80.8 - 124.0	69.6	13.0
	Females tangle net	23	68.4	53.3 - 82.2	8.7	–
	Males total	159	99.5	72.1 - 128.4	69.8	25.8
	Females total	159	65.8	50.6 - 82.2	8.2	–

Table 4: Number of *Chionoecetes opilio*, *Hyas spp* and *Cancer irroratus* larvae sampled by vertical tow in Bonne Bay- 1988 and 1989. The number of larvae was standardized to 100 m^3 of water filtered.

	Chionoecetes opilio			***Hyas spp***			***Cancer irroratus***	
Date	zoe I	zoe II	megalope	zoe I	zoe II	megalope	zoe I-V	megalope
May 88								
03	1	0	0	0	0	0	0	0
16	18	0	0	0	0	0	0	0
23	59	0	0	0	0	0	0	0
27	50	0	0	0	0	0	0	0
June 88								
01	17	0	0	1	0	0	0	0
11	12	0	0	17	0	0	0	0
13	8	0	0	7	0	0	0	0
July 88								
16	.2	0	0	.9	0	0	34	0
18	0	0	0	.4	.1	0	74	0
Aug 88								
24	0	0	0	0	0	.5	5	25
April 89								
22	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
May 89								
08	1	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
15	.2	0	0	.2	0	0	0	0
19	0	0	0	0	0	0	0	0
24	3	0	0	0	0	0	0	0
26	32	0	0	0	0	0	0	0
30	26	0	0	4	0	0	0	0
June 89								
08	78	0	0	11	0	0	0	0
09	17	0	0	8	0	0	0	0
23	44	0	0	5	0	0	0	0
26	26	0	0	3	0	0	0	0
July 89								
17	.4	0	0	.4	0	0	9	0
Sept 89								
05	0	0	0	0	0	0	6	11

Table 5: Fluctuations of the catch (in number) per unit of effort for male and female snow crab (*C. opilio*) caught by trap, tangle net, dive and trawl in Bonne Bay between 1984 and 1990.

Year			N male	N female	Effort*	CPUE male**	CPUE female**
Trap	1985		160	154	3	53.33	51.33
	1987		264	51	47	5.62	1.09
	1988		1204	2050	91	13.23	22.53
	1989		1530	532	122	12.54	4.36
	1990		2134	6	70	30.49	0.09
Tangle net	1987		75	10	9	8.33	1.11
	1987	couple	36	36	9	4.00	4.00
	1988		248	105	35	7.09	3.00
	1988	couple	42	42	17	2.47	2.47
	1989		1950	605	88	22.16	6.88
	1989	couple	333	333	81	4.11	4.11
	1990		794	46	70	11.34	0.66
	1990	couple	23	23	66	0.35	0.35
Dive	1984		28	28	2	14.00	14.00
	1985		3	3	1	3.00	3.00
	1987		28	28	8	3.50	3.50
	1988		44	44	6	7.33	7.33
	1989		235	235	16	14.69	14.69
	1990		136	136	12	11.33	11.33
Trawl	1985		2044	3049	24	85.17	127.04
	1988		342	275	5	68.40	55.00
	1989		762	775	10	76.20	77.50
	1990		1354	1484	19	71.26	78.11

N: number

* Trap: number of trap haul
Tangle net: number of tangle net haul
Dive: number of dive (two divers per dive)
Trawl: number of tow

** CPUE: Catch (number of crab) Per Unit of Effort

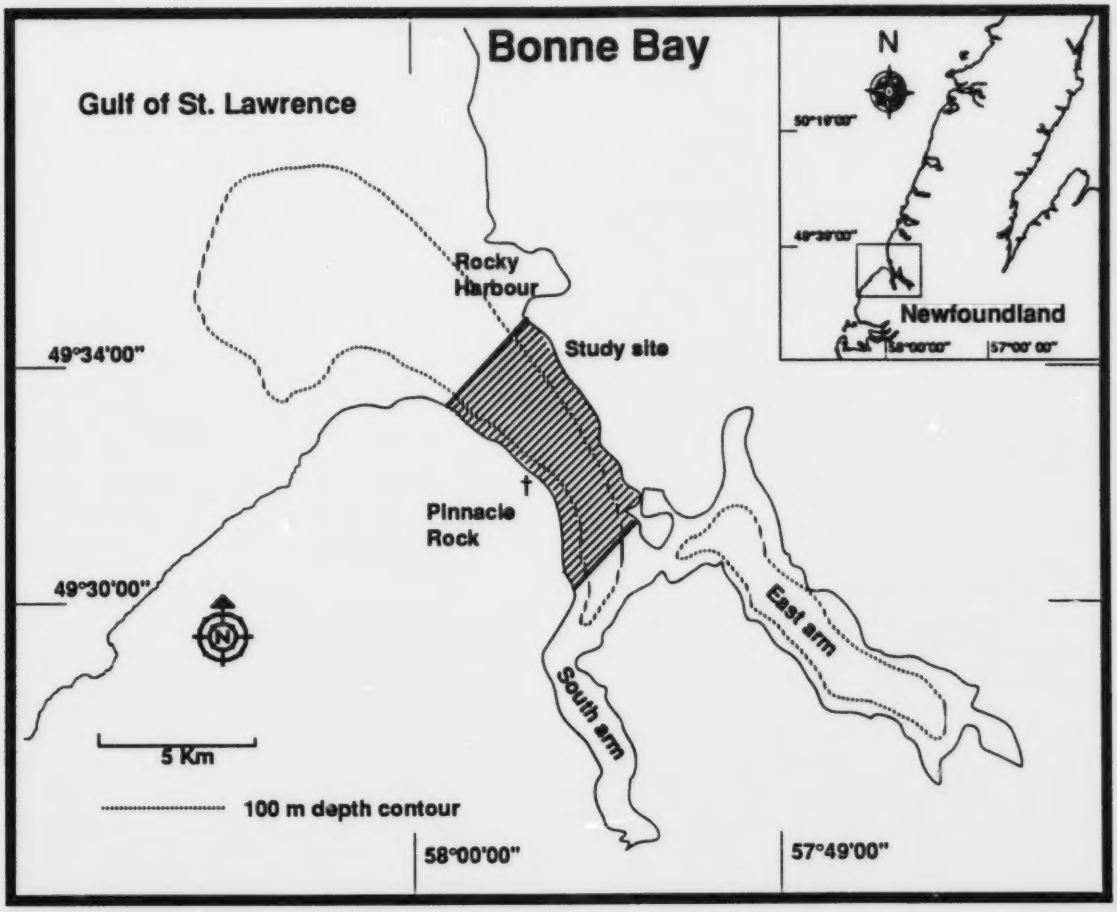

Figure 1. Location of the study site in Bonne Bay, Newfoundland.

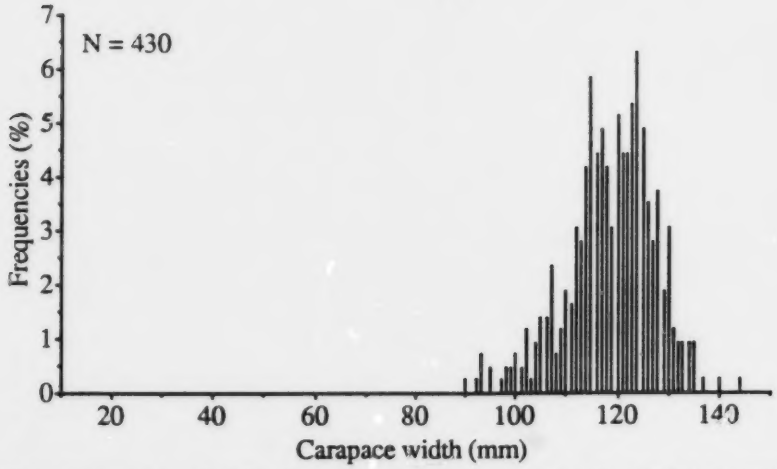

Figure 2. Size frequency distribution for male snow crab (*C. opilio*) caught by trap in Bonne Bay - 1983.

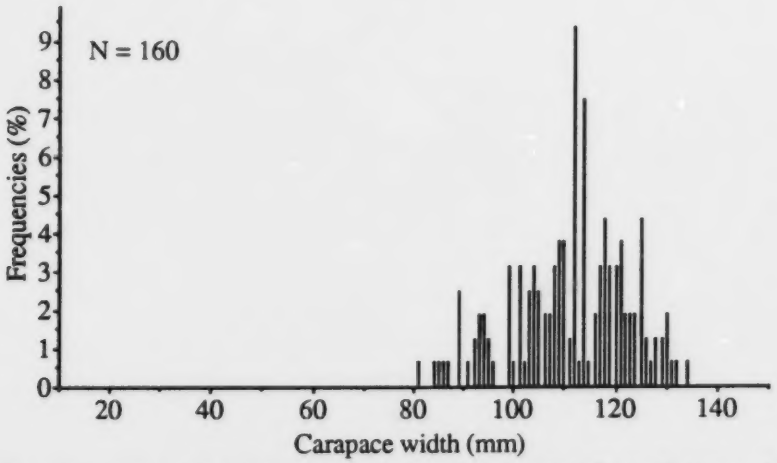

Figure 3. Size frequency distribution for male snow crab (*C. opilio*) caught by trap in Bonne Bay - 1985.

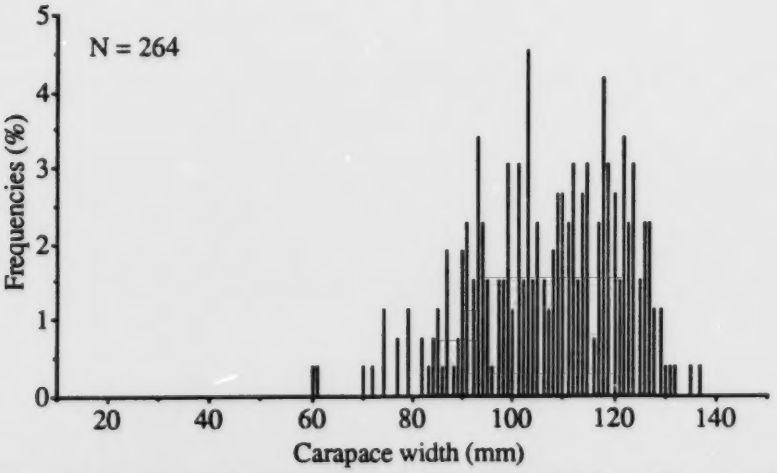

Figure 4. Size frequency distribution for male snow crab (*C. opilio*) caught by trap in Bonne Bay - 1987.

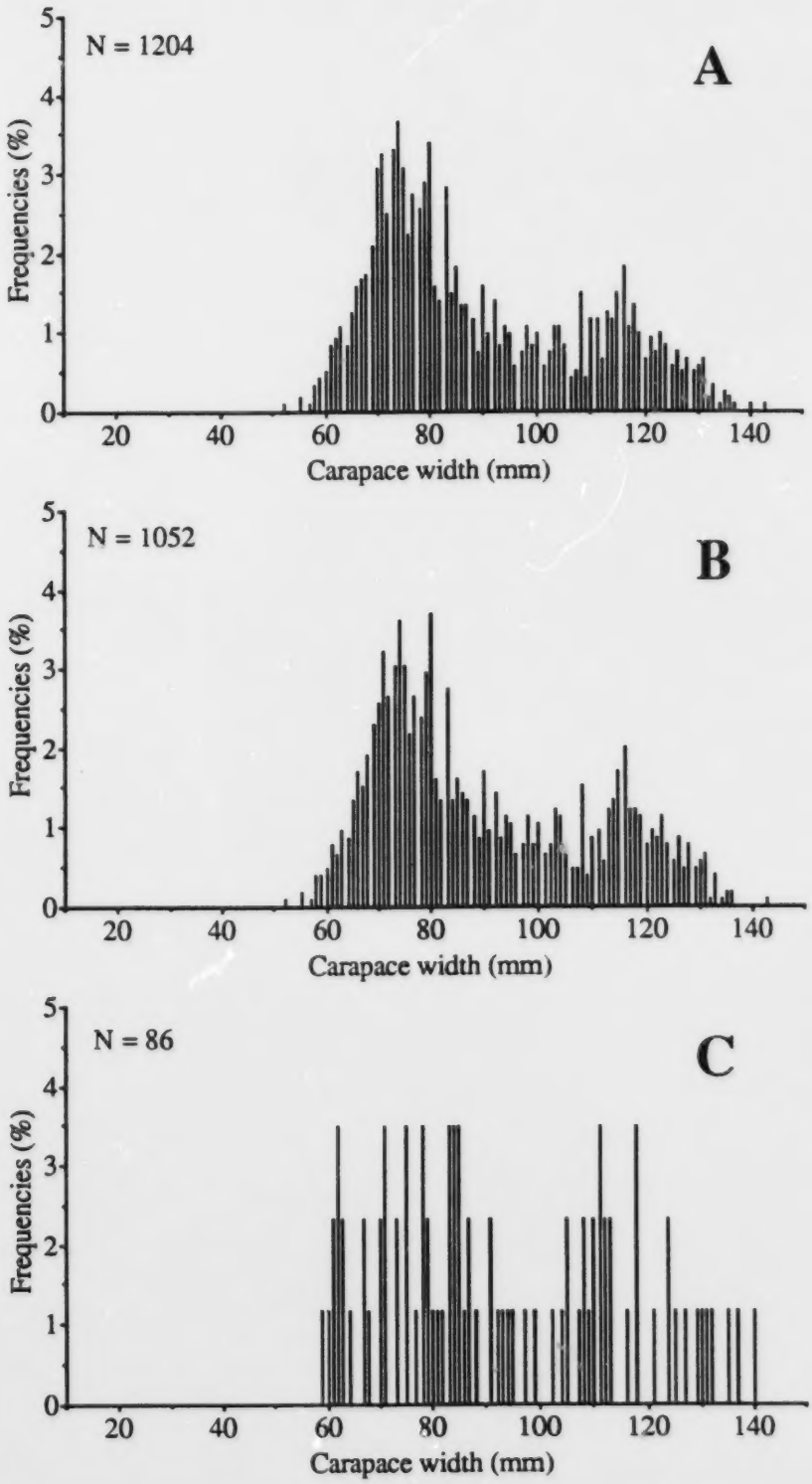

Figure 5. Size frequency distributions for male snow crab (*C. opilio*) caught by trap in Bonne Bay - 1988: A) Total, B) New-shell, C) Old-shell.

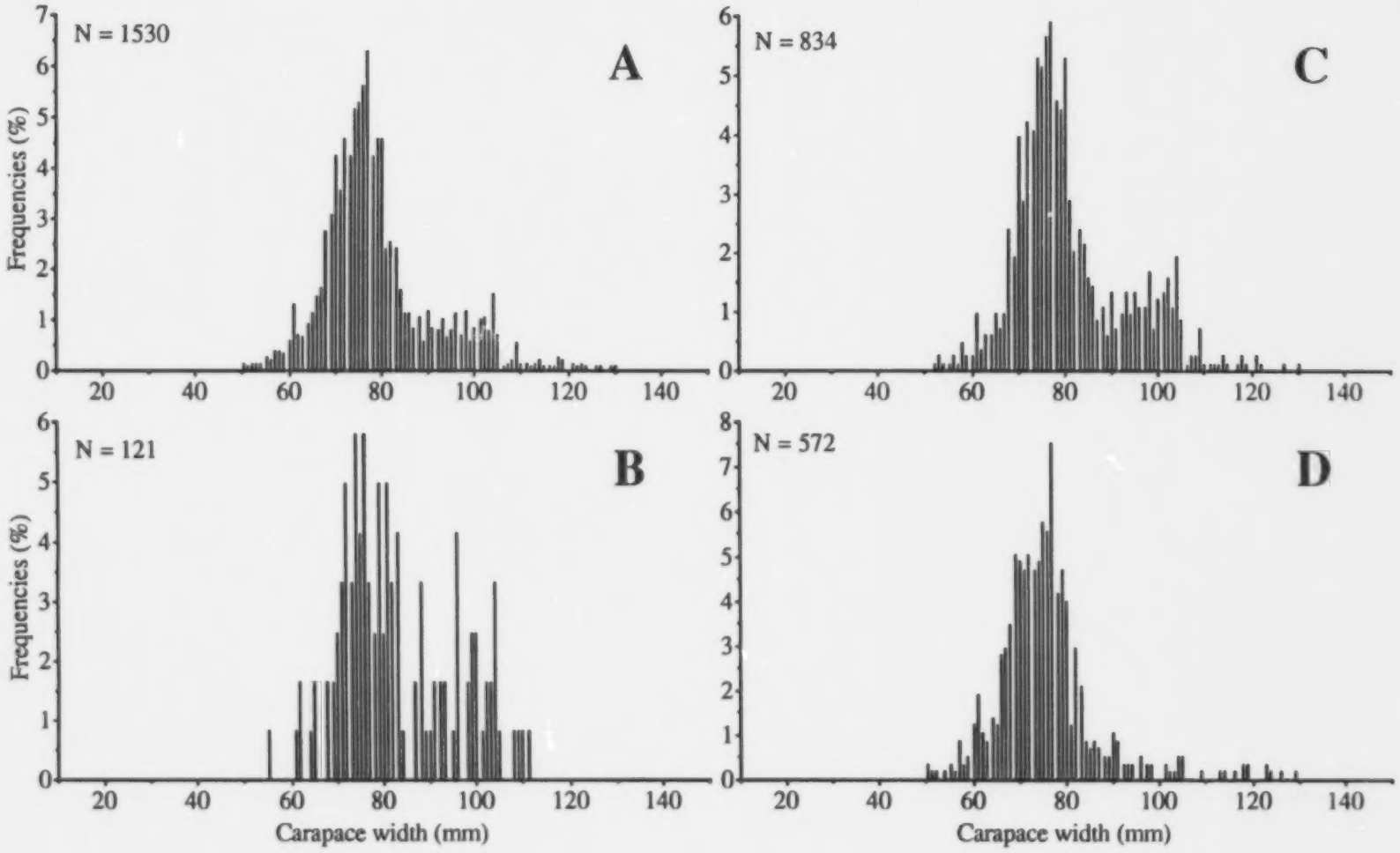

Figure 6. Size frequency distributions for male snow crab (*C. opilio*) caught by trap in Bonne Bay - 1989: A) Total, B) White-shell, C) New-shell, D) Old-shell.

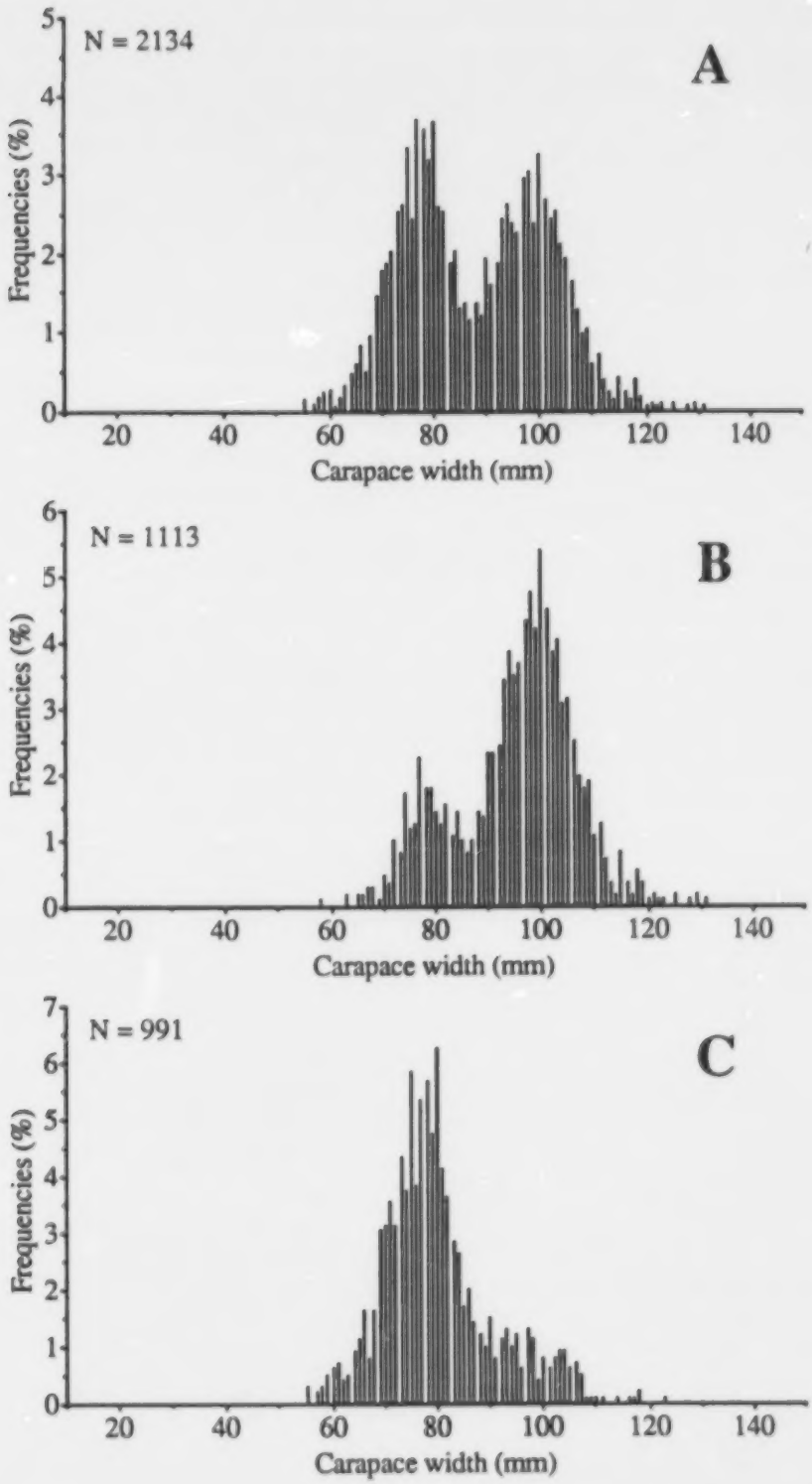

Figure 7. Size frequency distributions for male snow crab (*C. opilio*) caught by trap in Bonne Bay - 1990: A) Total, B) New-shell, C) Old-shell.

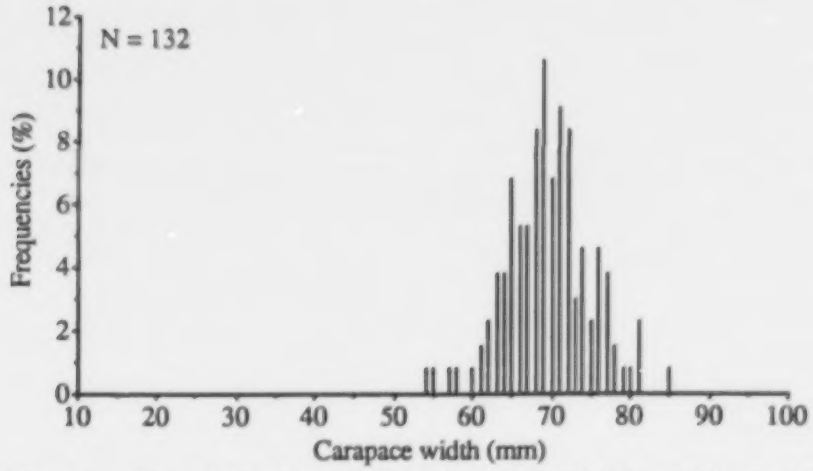

Figure 8. Size frequency distribution for female snow crab (*C. opilio*) caught by trap in Bonne Bay - 1983.

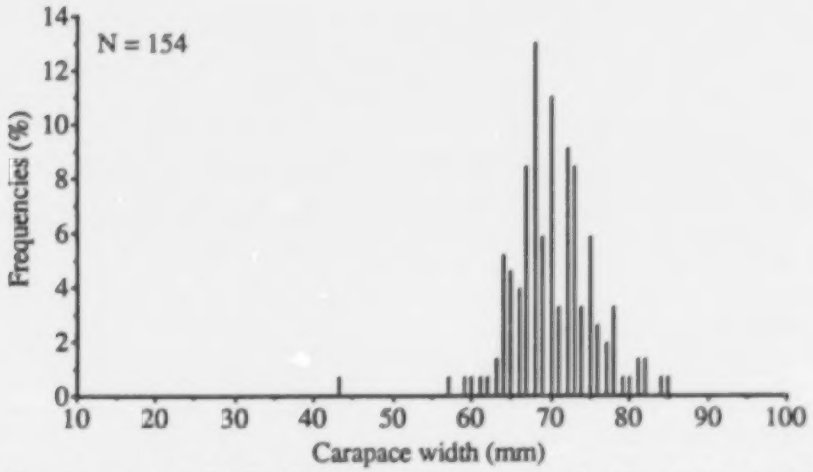

Figure 9. Size frequency distribution for female snow crab (*C. opilio*) caught by trap in Bonne Bay - 1985.

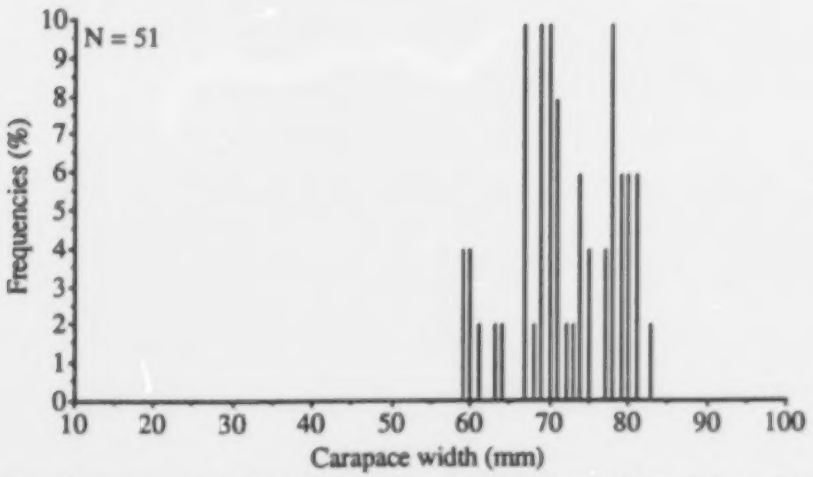

Figure 10. Size frequency distribution for female snow crab (*C. opilio*) caught by trap in Bonne Bay - 1987.

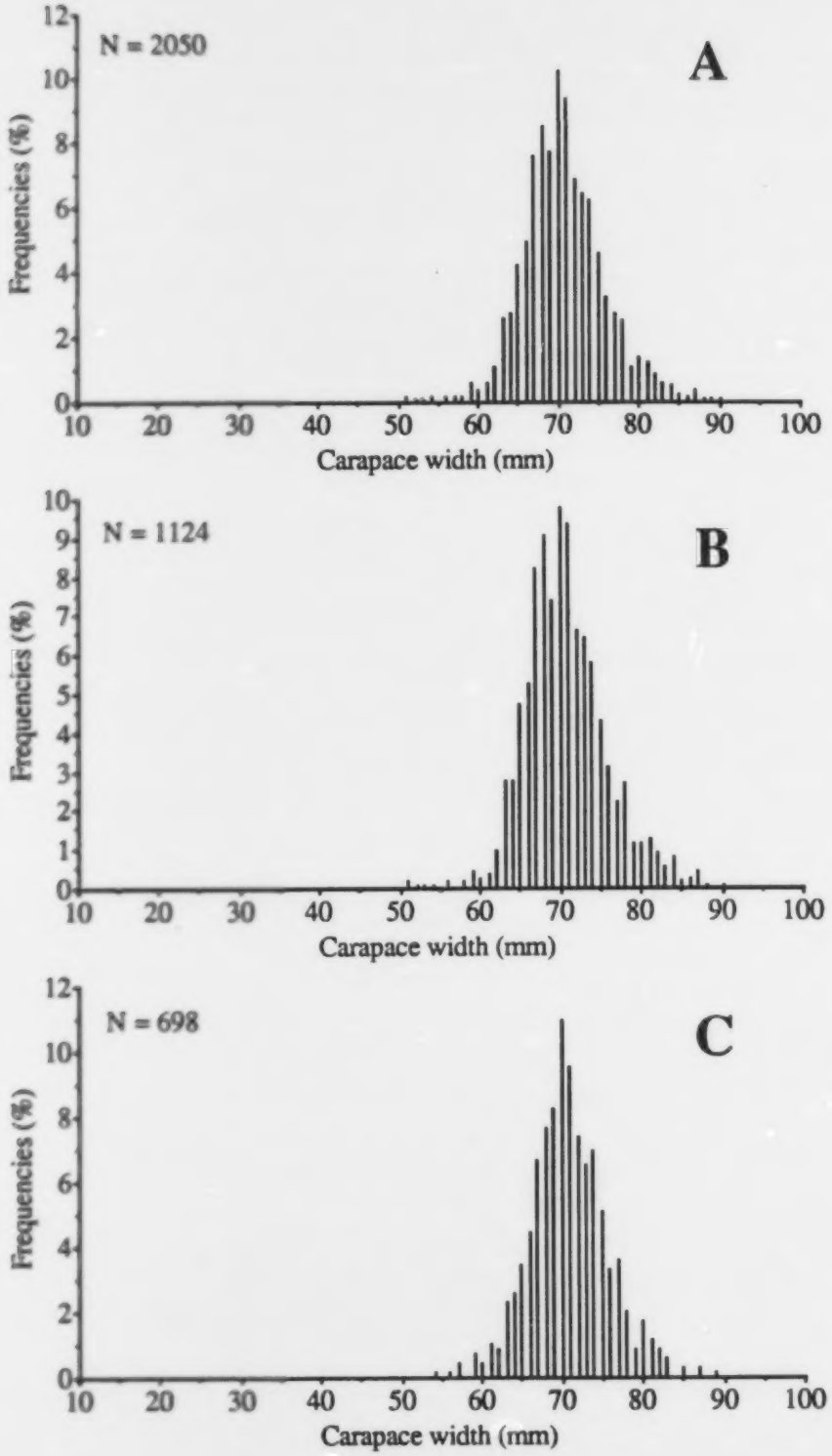

Figure 11. Size frequency distributions for female snow crab (*C. opilio*) caught by trap in Bonne Bay - 1988: A) Total, B) New-shell, C) Old-shell.

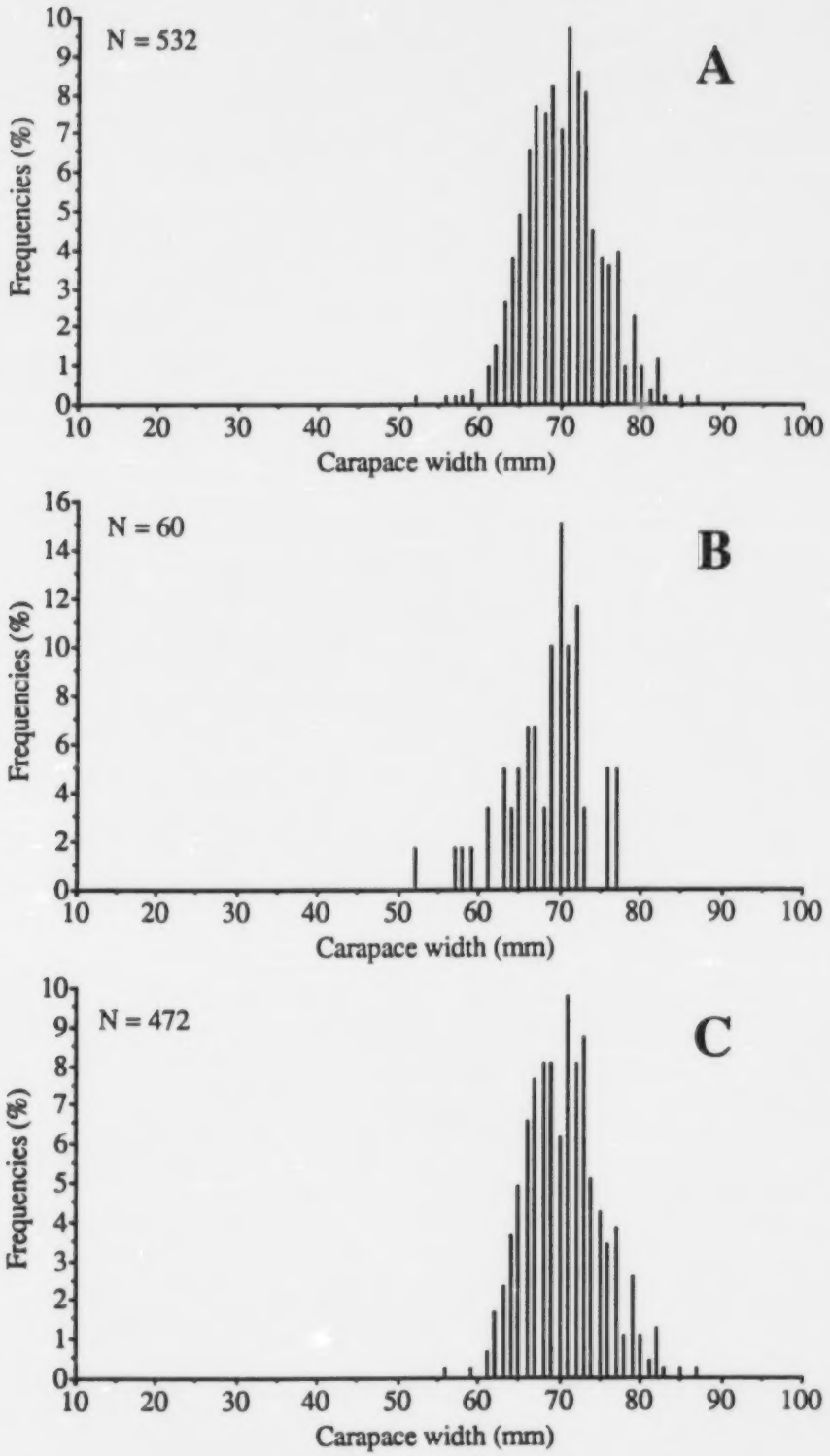

Figure 12. Size frequency distributions for female snow crab (*C. opilio*) caught by trap in Bonne Bay - 1989: A) Total, B) New-shell, C) Old-shell.

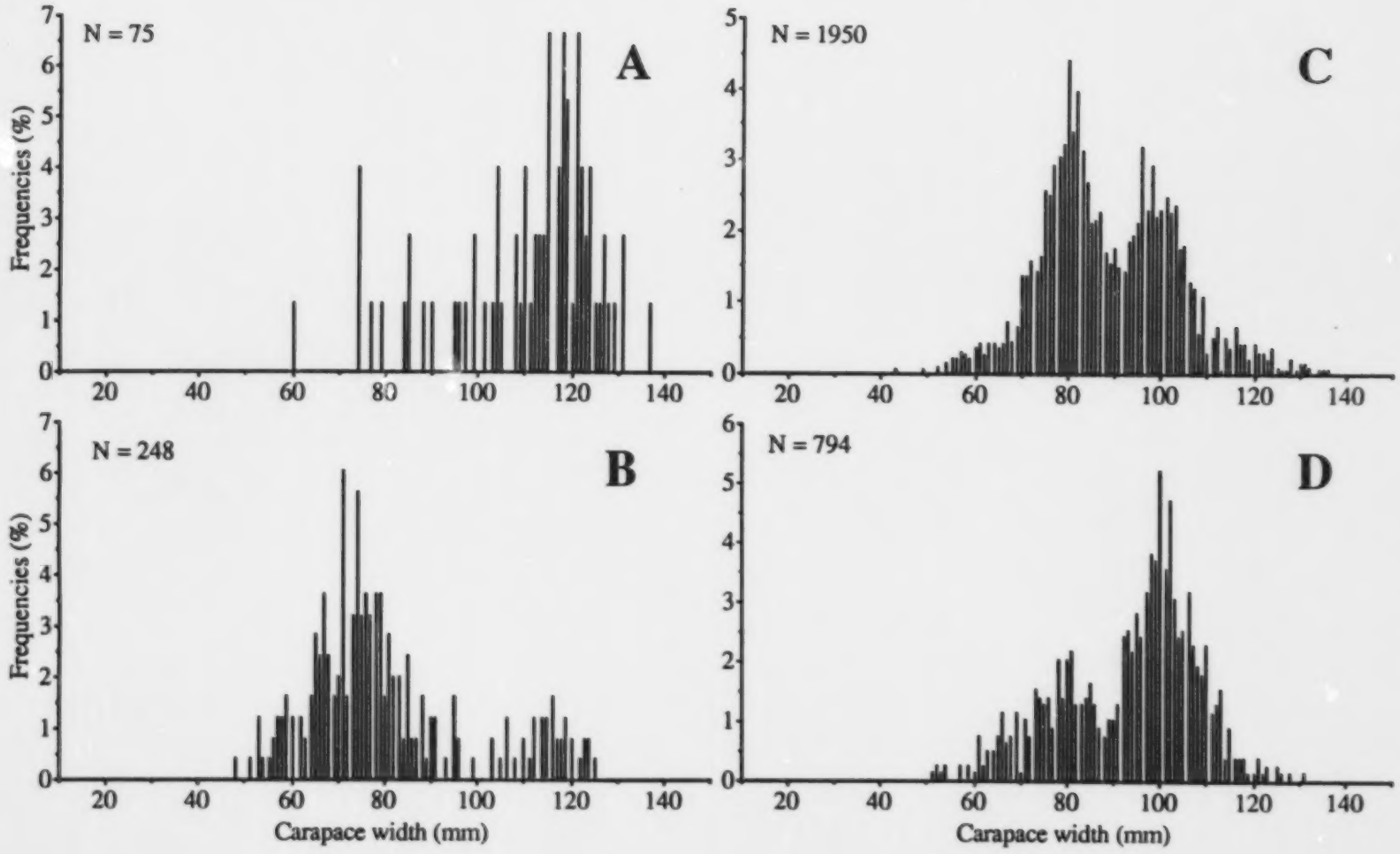

Figure 13. Size frequency distributions for male snow crab (*C. opilio*) caught by tangle net in Bonne Bay: A) 1987, B) 1988, C) 1989, D) 1990.

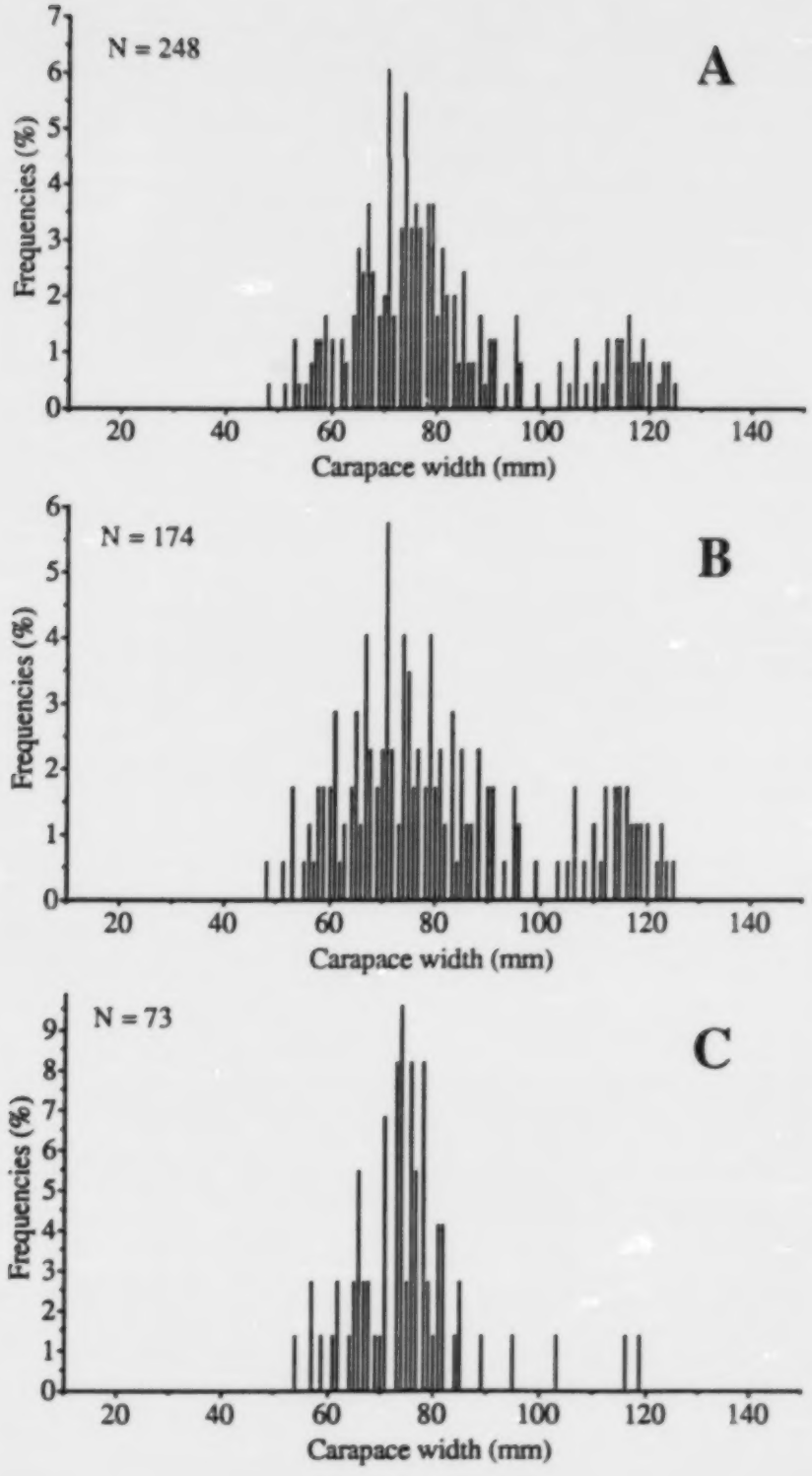

Figure 14. Size frequency distributions for male snow crab (*C. opilio*) caught by tangle net in Bonne Bay - 1988: A) Total, B) New-shell, C) Old-shell.

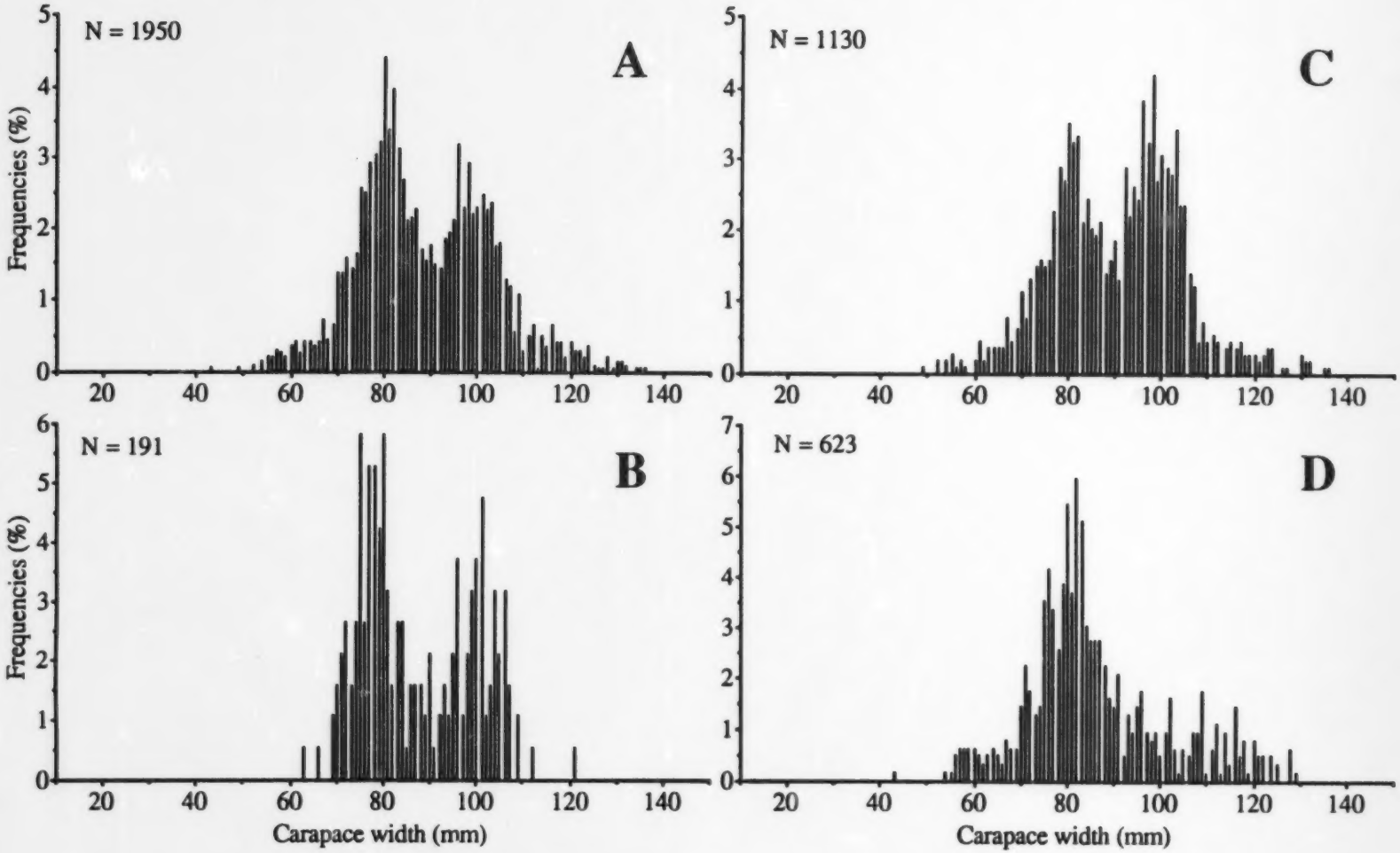

Figure 15. Size frequency distributions for male snow crab (*C. opilio*) caught by tangle net in Bonne Bay - 1989: A) Total, B) White-shell, C) New-shell, D) Old-shell.

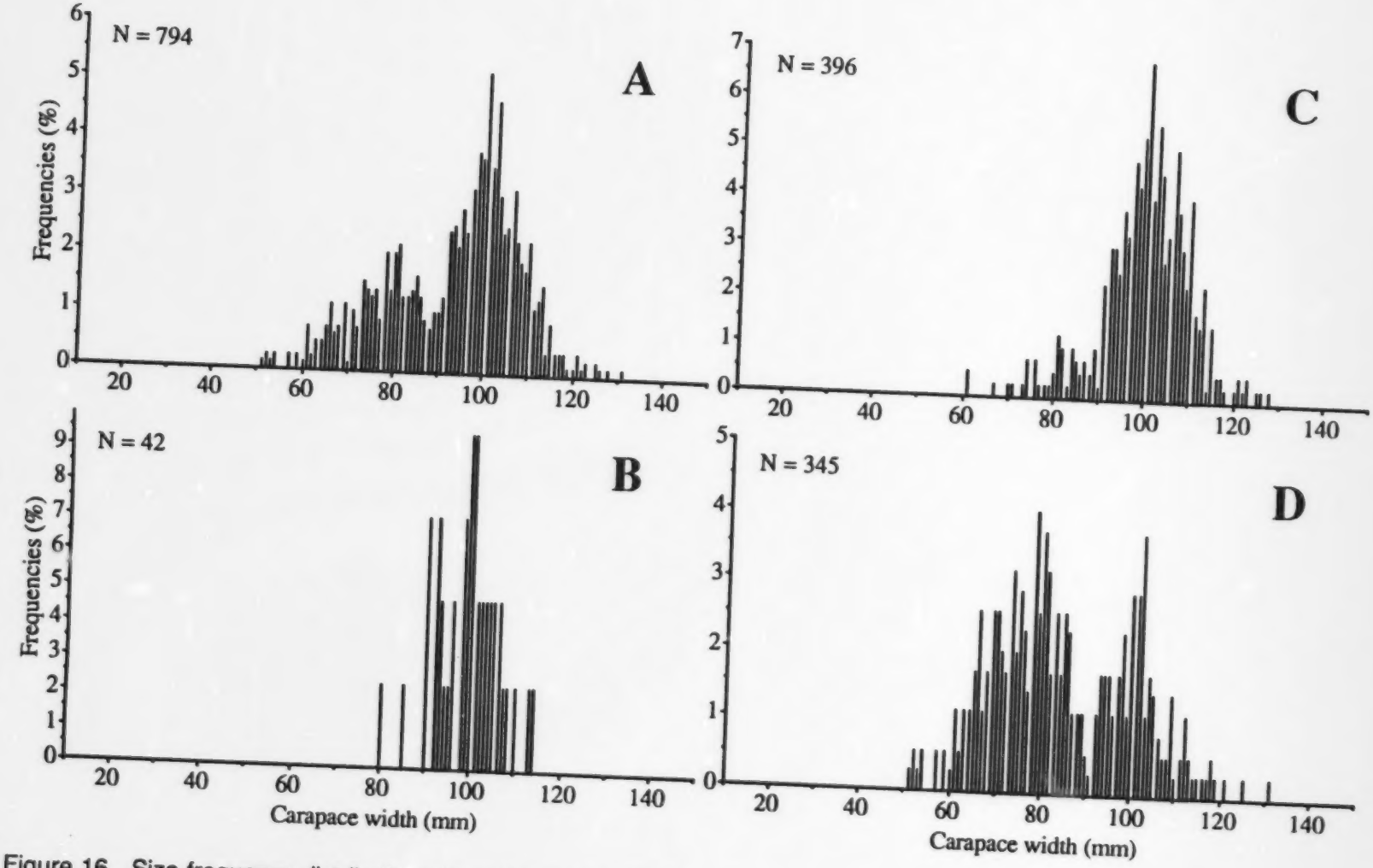

Figure 16. Size frequency distributions for male snow crab (*C. opilio*) caught by tangle net in Bonne Bay - 1990: A) Total, B) White-crab, C) New-shell, D) Old-shell.

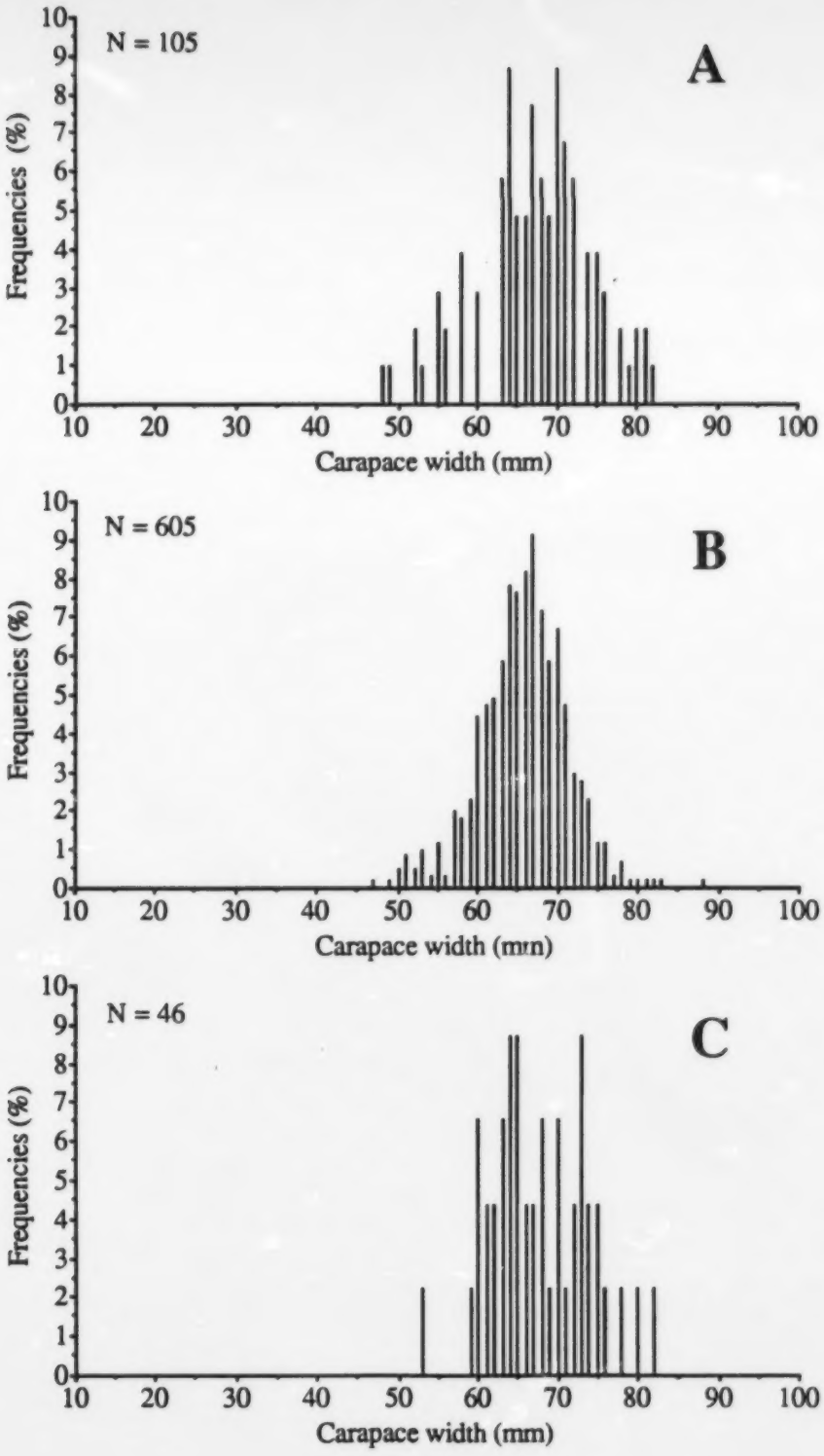

Figure 17. Size frequency distributions for female snow crab (*C. opilio*) caught by tangle net in Bonne Bay: A) 1988, B) 1989, C) 1990.

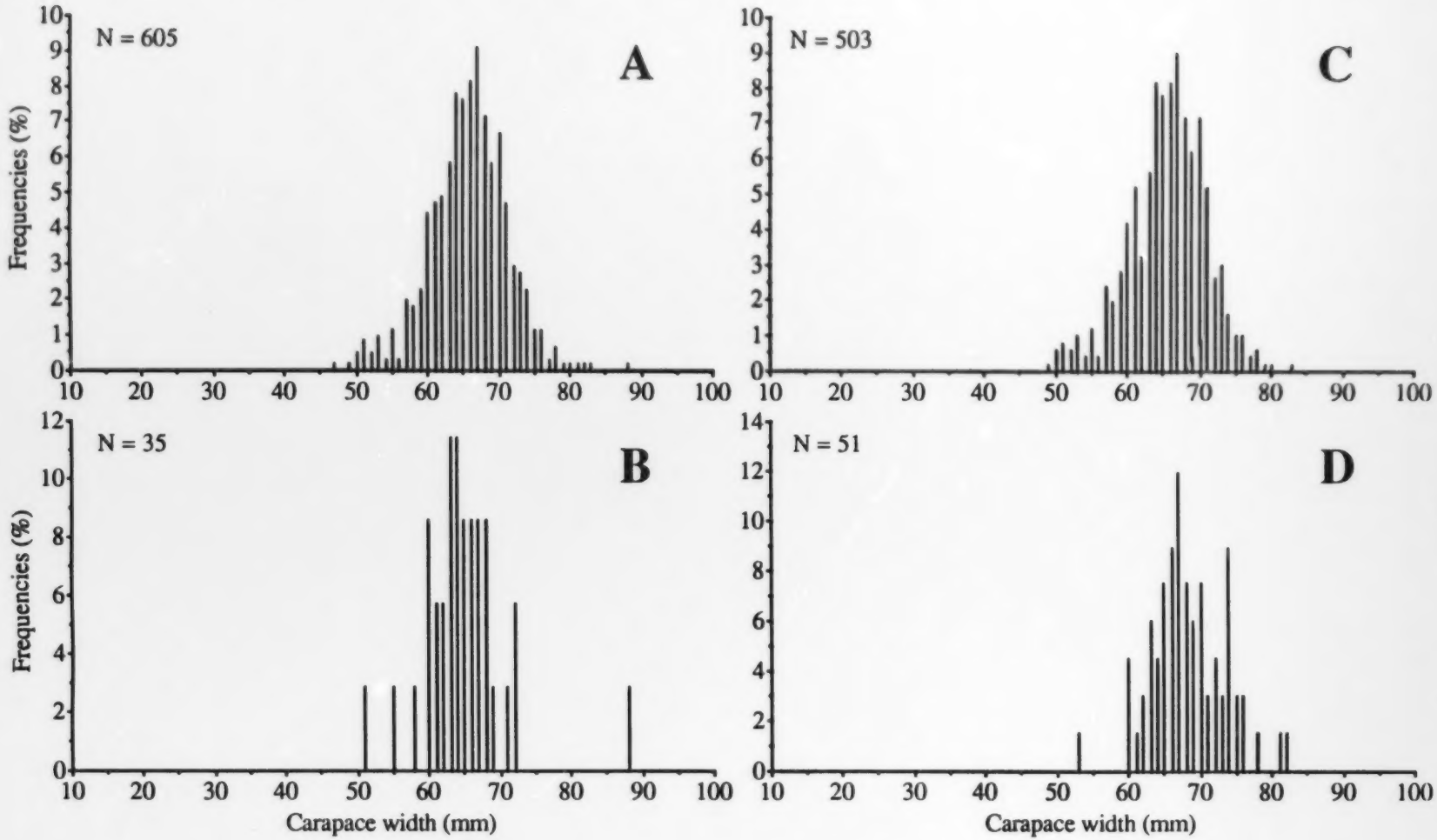

Figure 18. Size frequency distributions for female snow crab (*C. opilio*) caught by tangle net in Bonne Bay - 1989: A) Total, B) White-shell, C) New-shell, D) Old-shell.

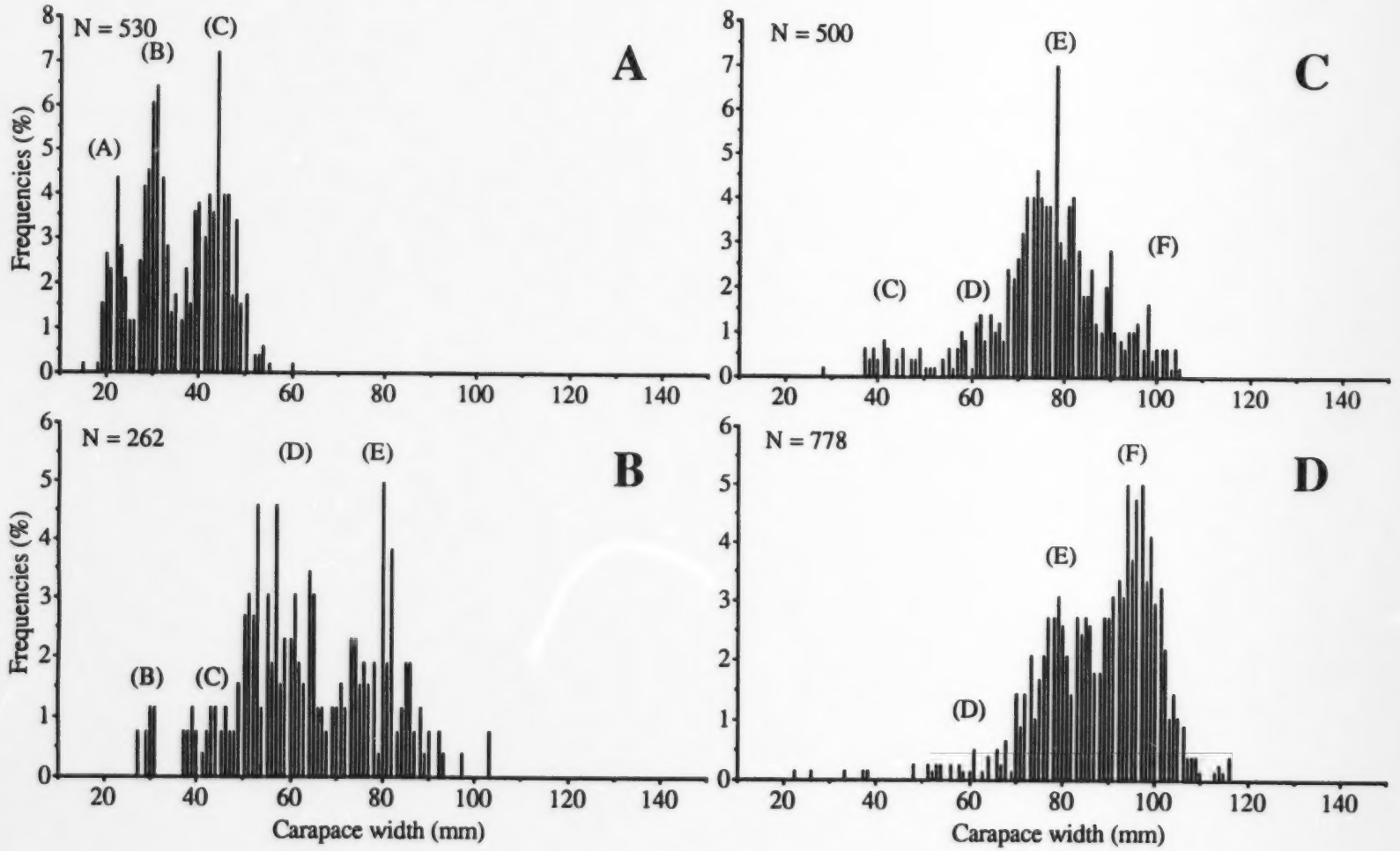

Figure 19. Size frequency distributions for juvenile male snow crab (*C. opilio*) caught by trawl in Bonne Bay: A) 1985, B) 1988, C) 1989, D) 1990. Major modes are indicated by the letter in parenthesis.

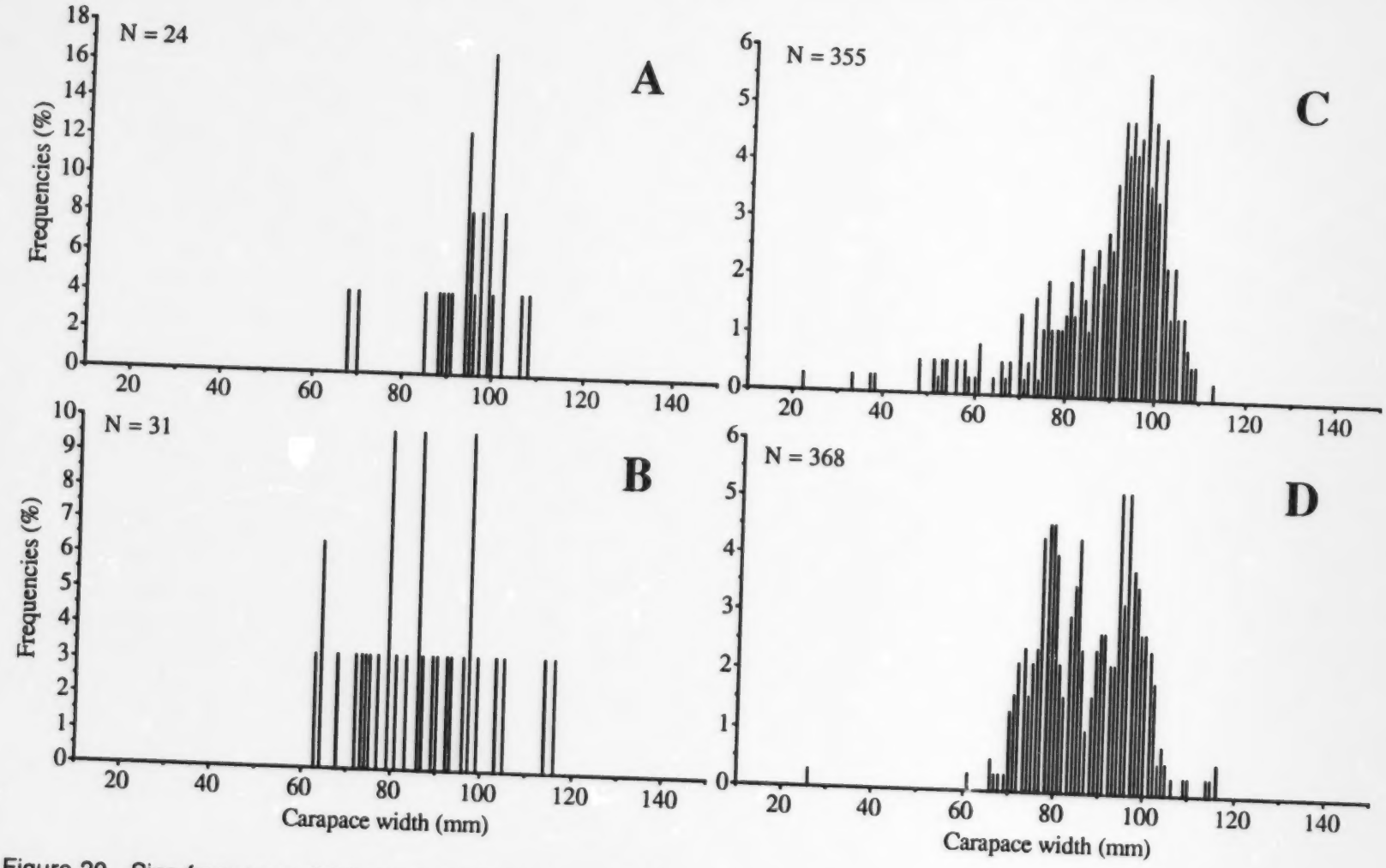

Figure 20. Size frequency distributions for juvenile male snow crab (*C. opilio*) caught by trawl in Bonne Bay - 1990: A) White-shell, B) Old-shell, C) New-shell, D) Medium-shell. The Medium-shell condition is attributed to a juvenile crab in premolt condition.

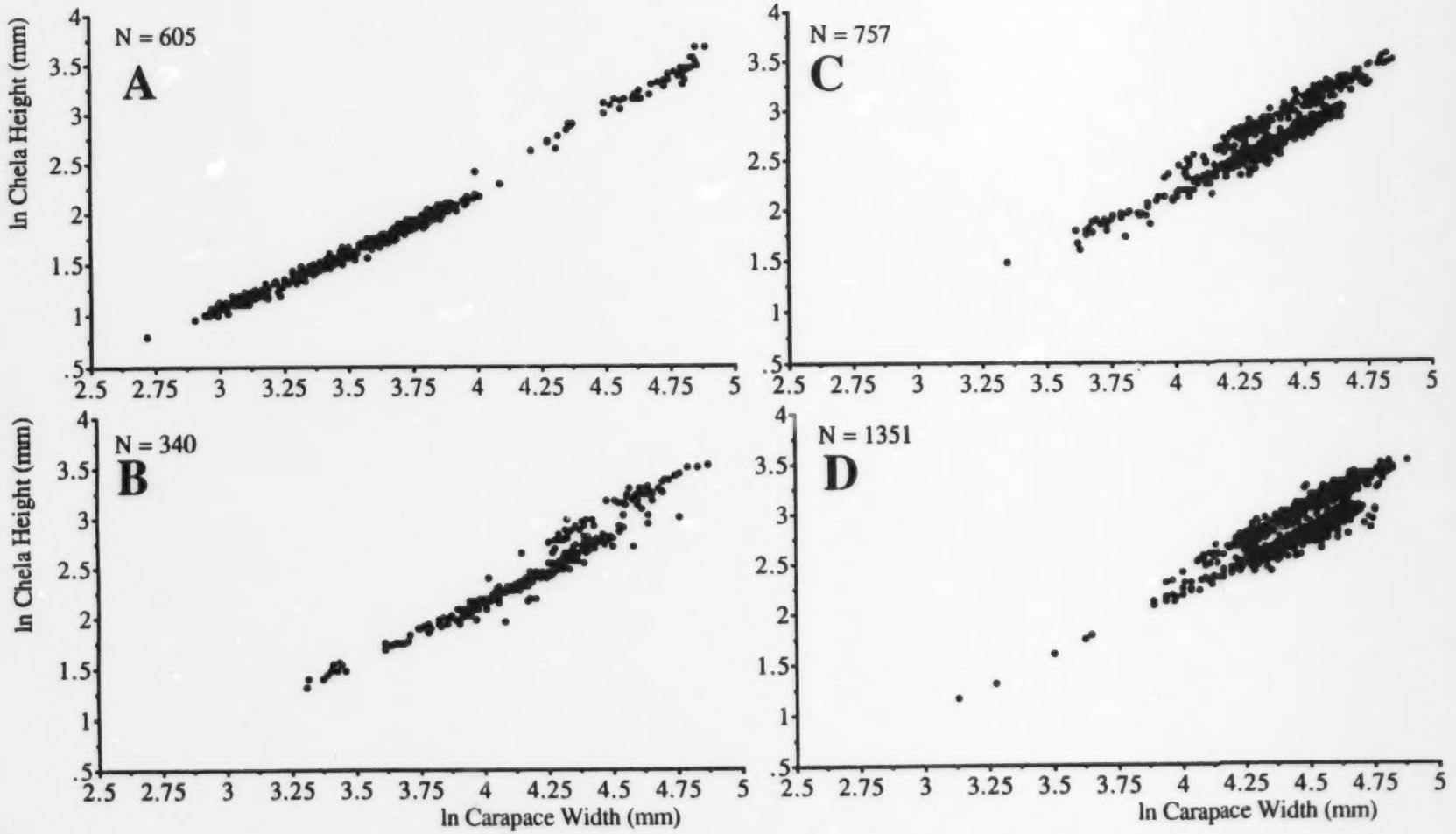

Figure 21. Chela height vs carapace width plotted on a logarithmic scale for male snow crab (*C. opilio*) caught by trawl in Bonne Bay: A) 1985 B) 1988, C) 1989, D) 1990. The upper swarm of points represent the morphometrically mature males and the lower swarm of points represent the immature/juvenile males.

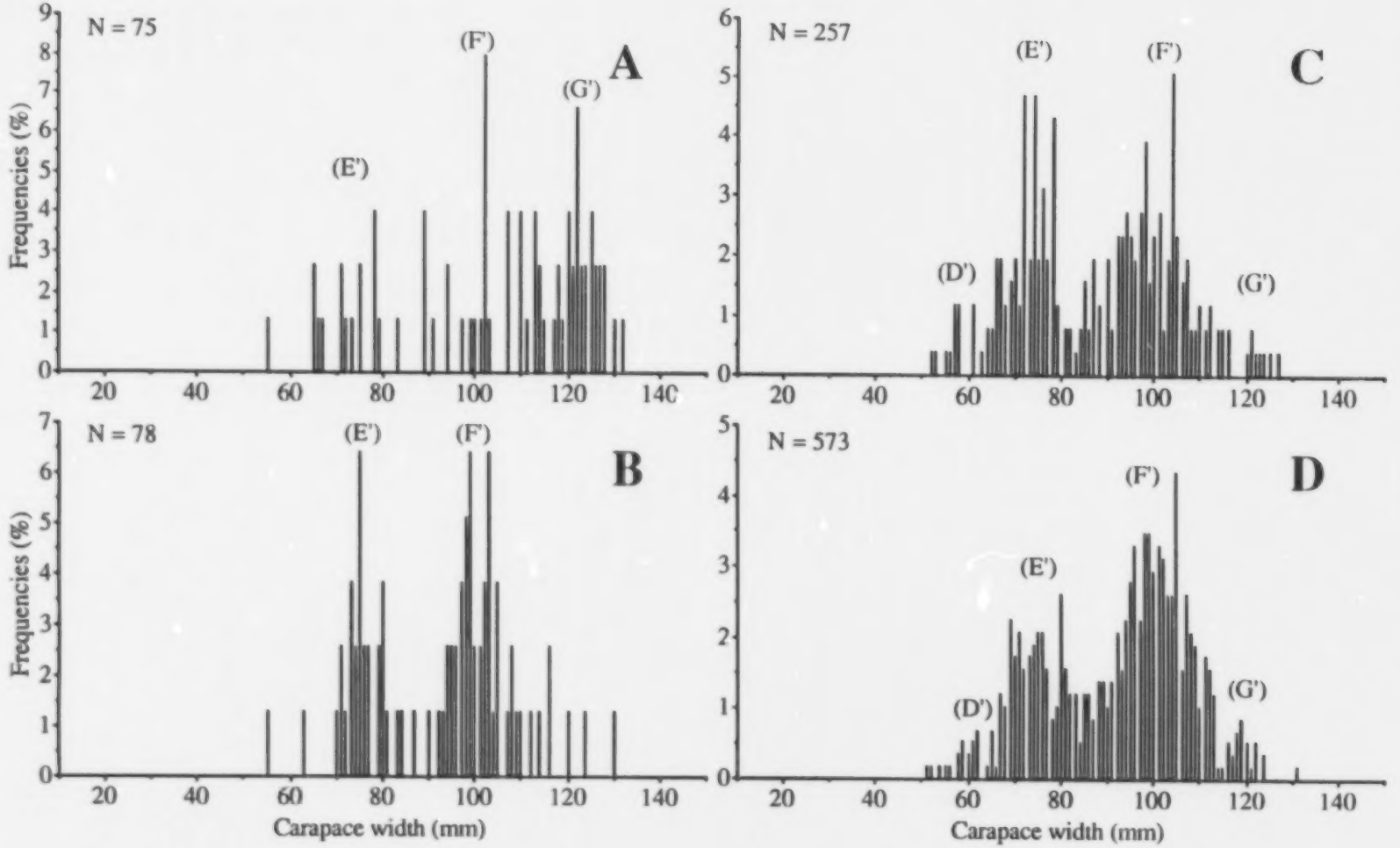

Figure 22. Size frequency distributions for morphometrically mature male snow crab (*C. opilio*) caught by trawl in Bonne Bay: A) 1985, B) 1988, C) 1989, D) 1990. Major modes are indicated by the letter in parenthesis.

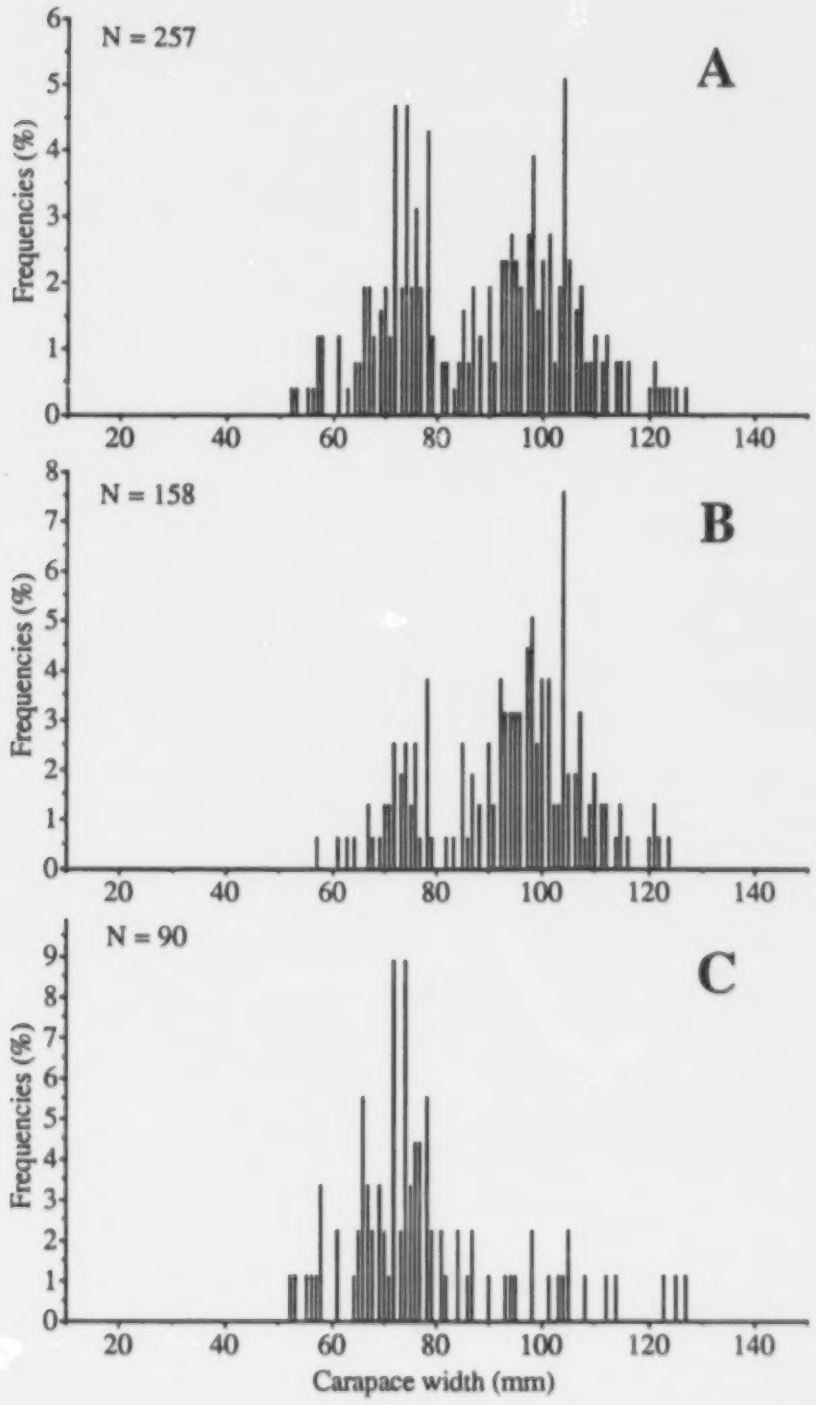

Figure 23. Size frequency distributions for morphometrically mature male snow crab (*C. opilio*) caught by trawl in Bonne Bay - 1989: A) Total, B) New-shell, C) Old-shell.

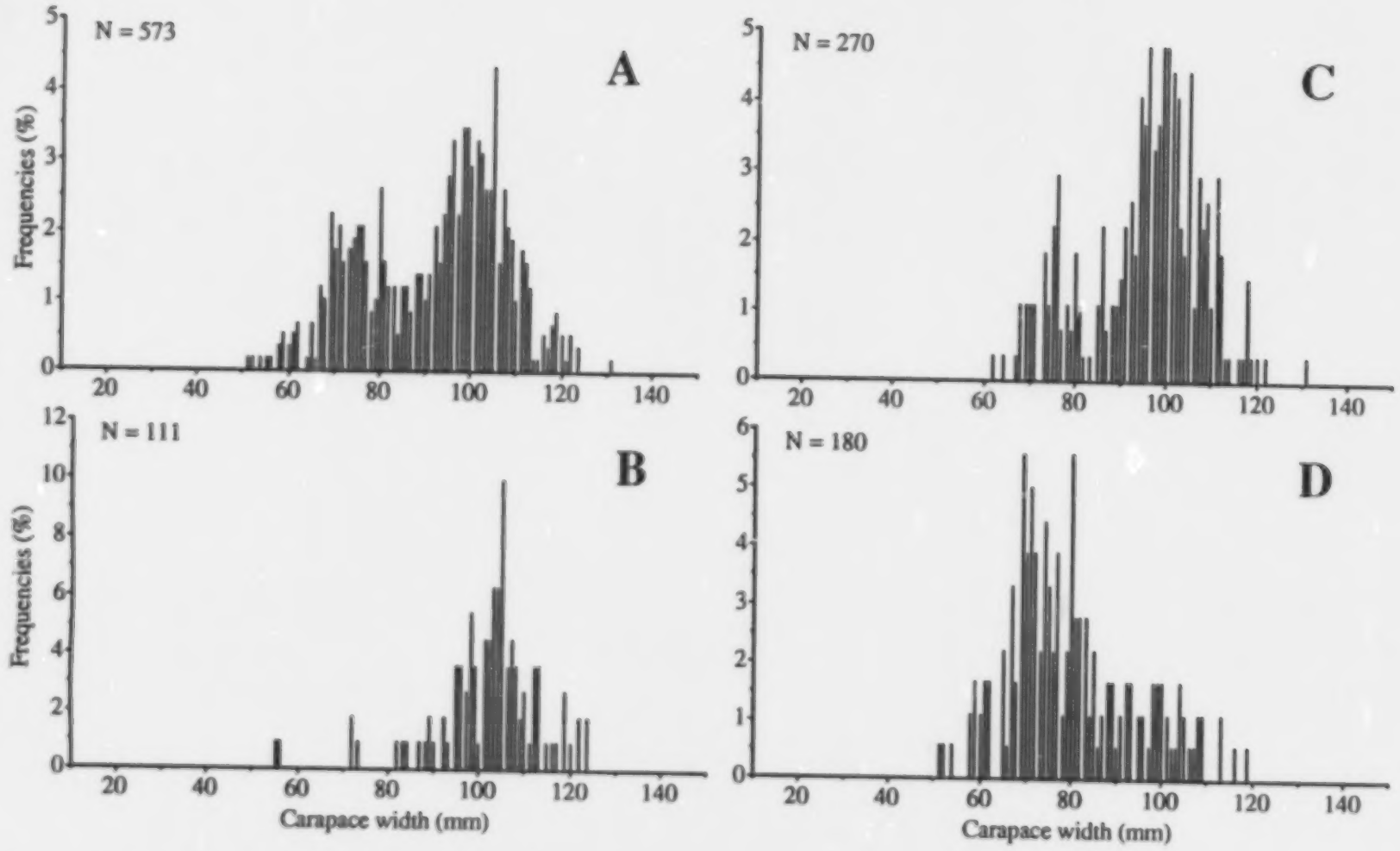

Figure 24. Size frequency distributions for morphometrically mature male snow crab (*C. opilio*) caught by trawl in Bonne Bay - 1990: A) Total, B) New-shell, C) Medium-shell, D) Old-shell.

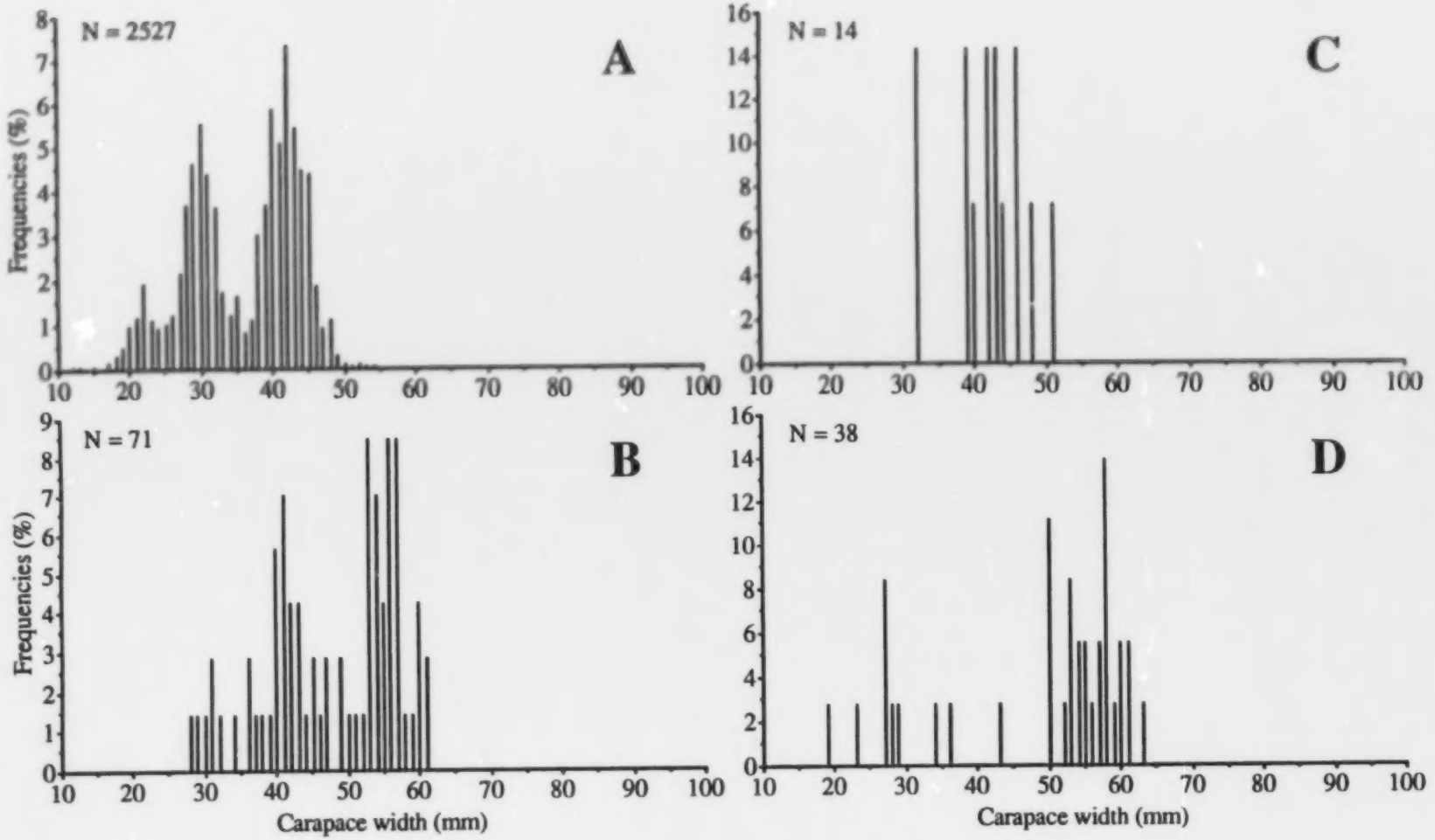

Figure 25. Size frequency distributions for immature female snow crab (*C. opilio*) caught by trawl in Bonne Bay: A) 1985, B) 1988, C) 1989, D) 1990.

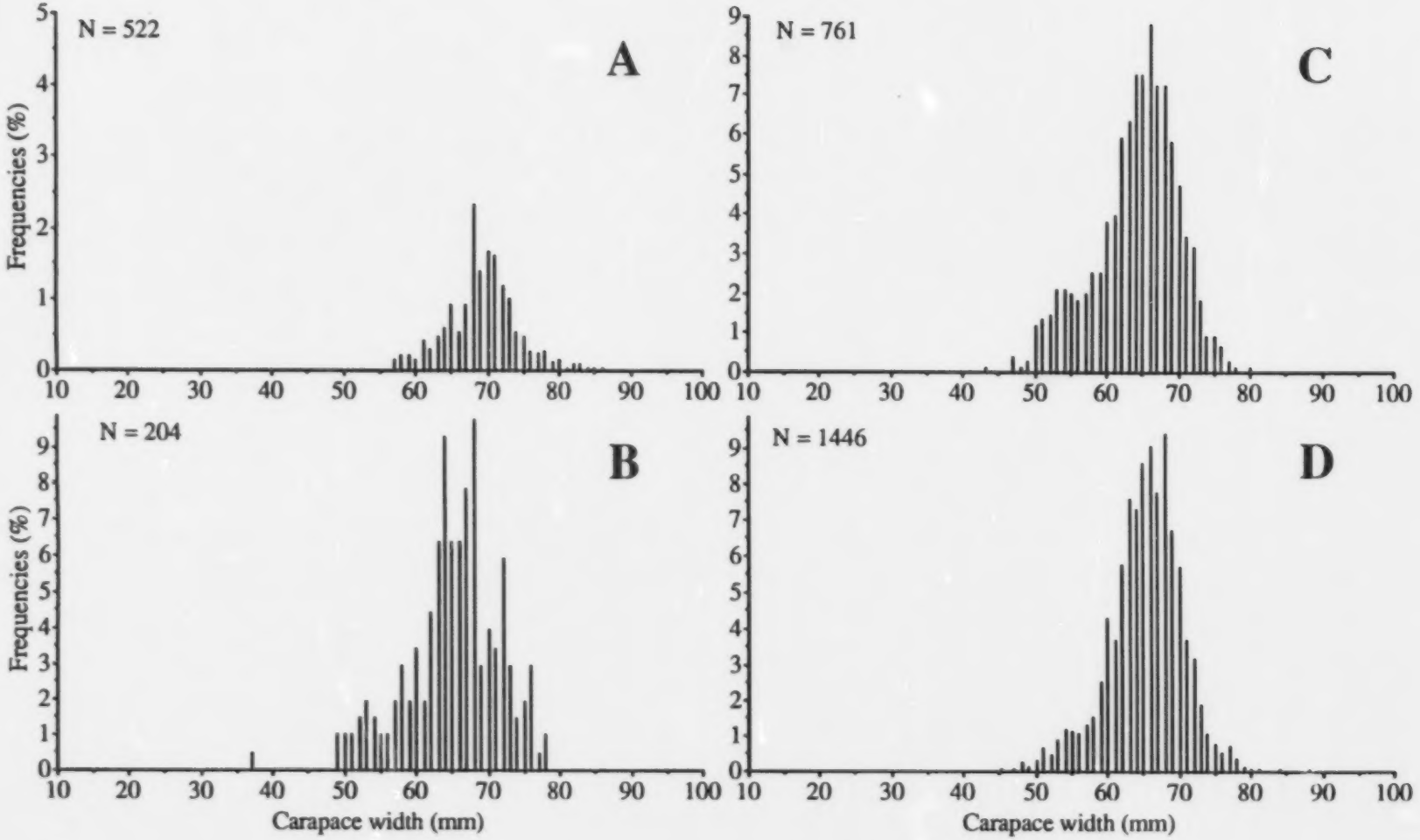

Figure 26. Size frequency distributions for mature female snow crab (*C. opilio*) caught by trawl in Bonne Bay: A) 1985, B) 1988, C) 1989, D) 1990.

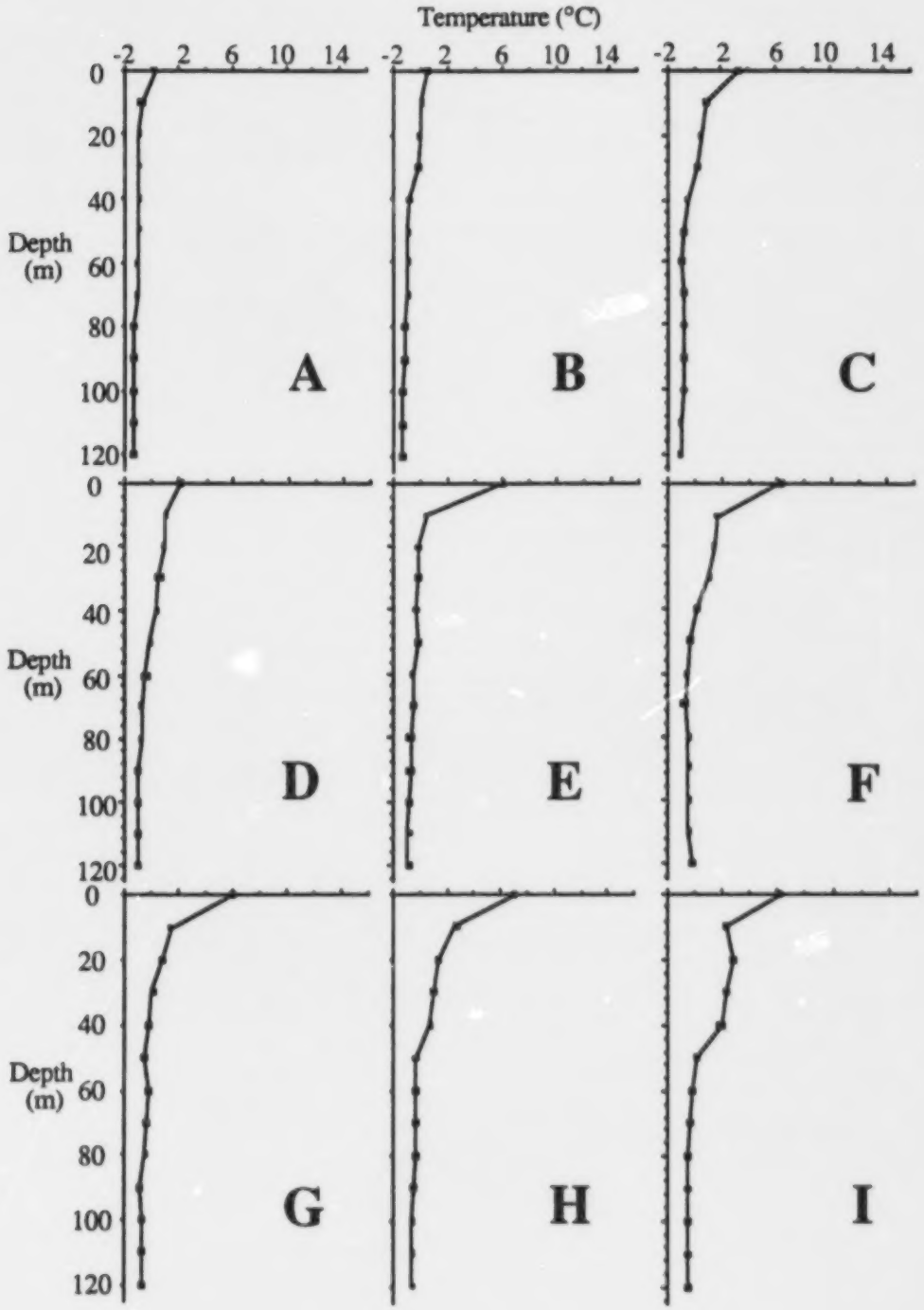

Figure 27. Temperature profiles obtained in Bonne Bay at the Pinnacle rock site in 1989: A) April 22, B) April 28, C) May 2, D) May 5, E) May 6, F) May 10, G) May 11, H) May 14, I) May 22, J) May 24, K) May 29, L) June 1, M) June 5, N) June 7, O) June 26,P) July 15, Q) July 17, R) Sept. 5.

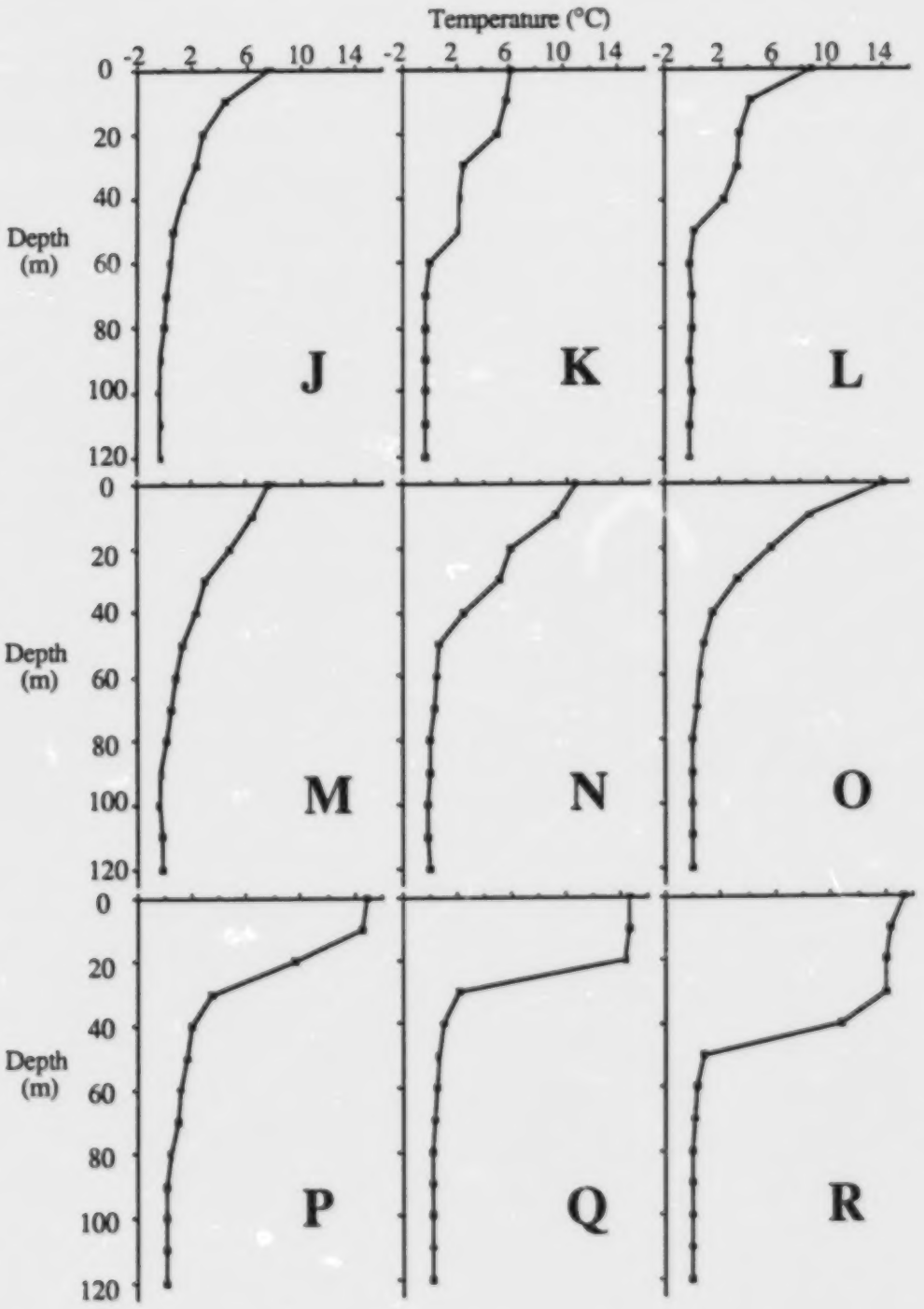

Figure 27. cont.

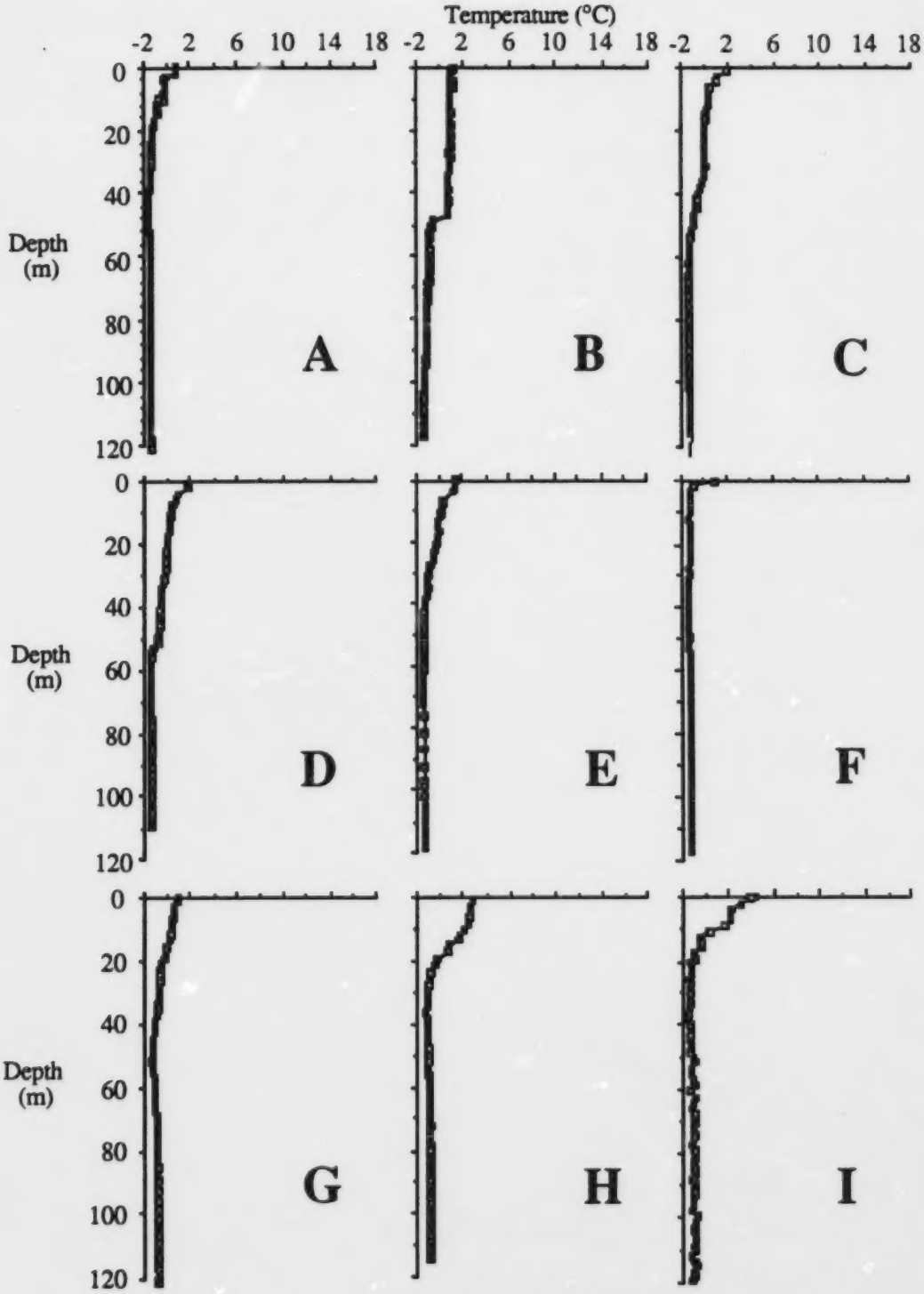

Figure 28. Temperature profiles obtained in Bonne Bay at the Pinnacle rock site in 1990: A) May 9, B) May 12, C) May 14, D) May 15, E) May 18, F) May 22, G) May 25, H) May 28, I) May 29, J) June 1, K) June 7, L) June 11, M) July 5, N) July 17, O) August 4, P) August 7, Q) August 12, R) August 22.

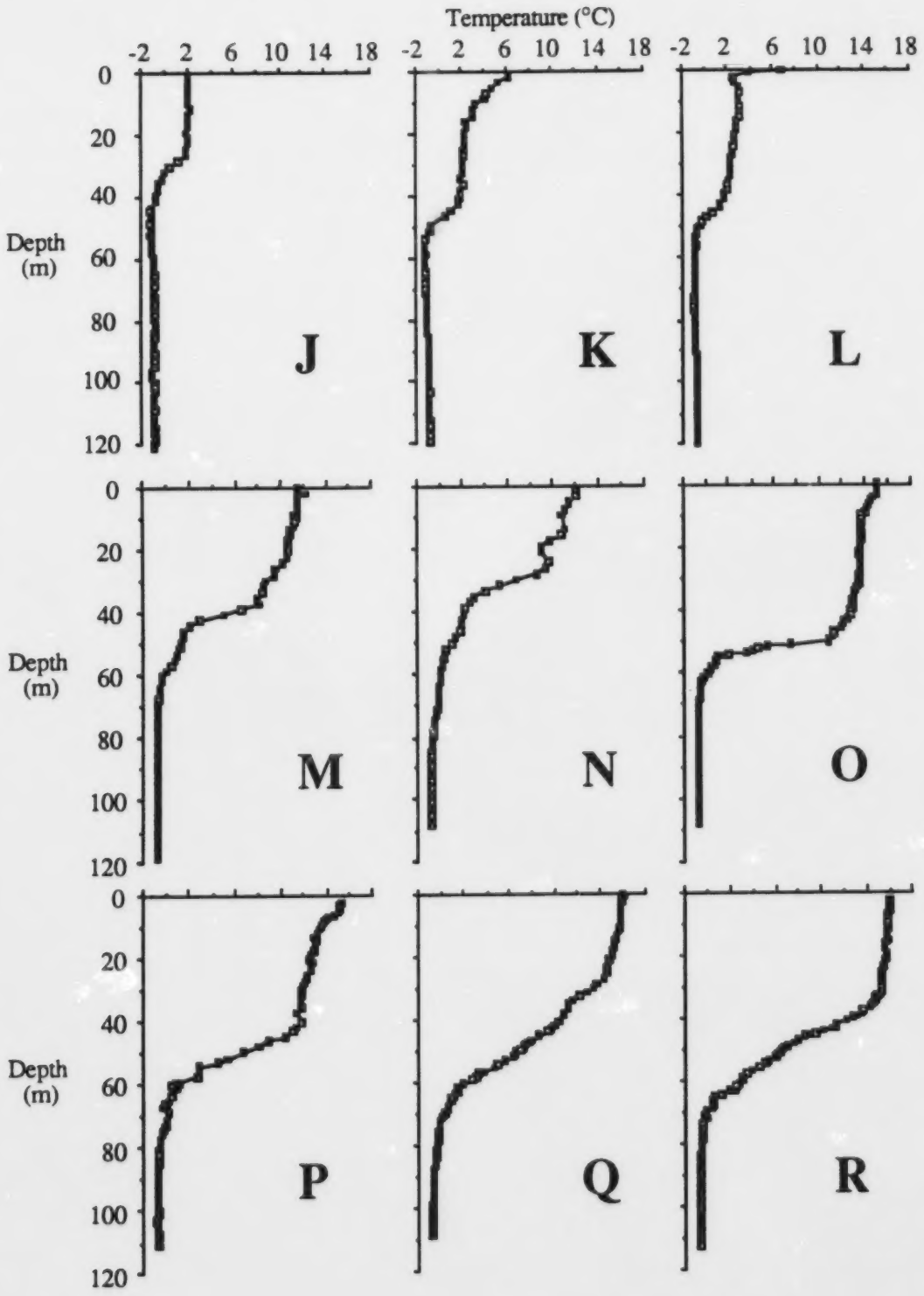

Figure 28. cont.

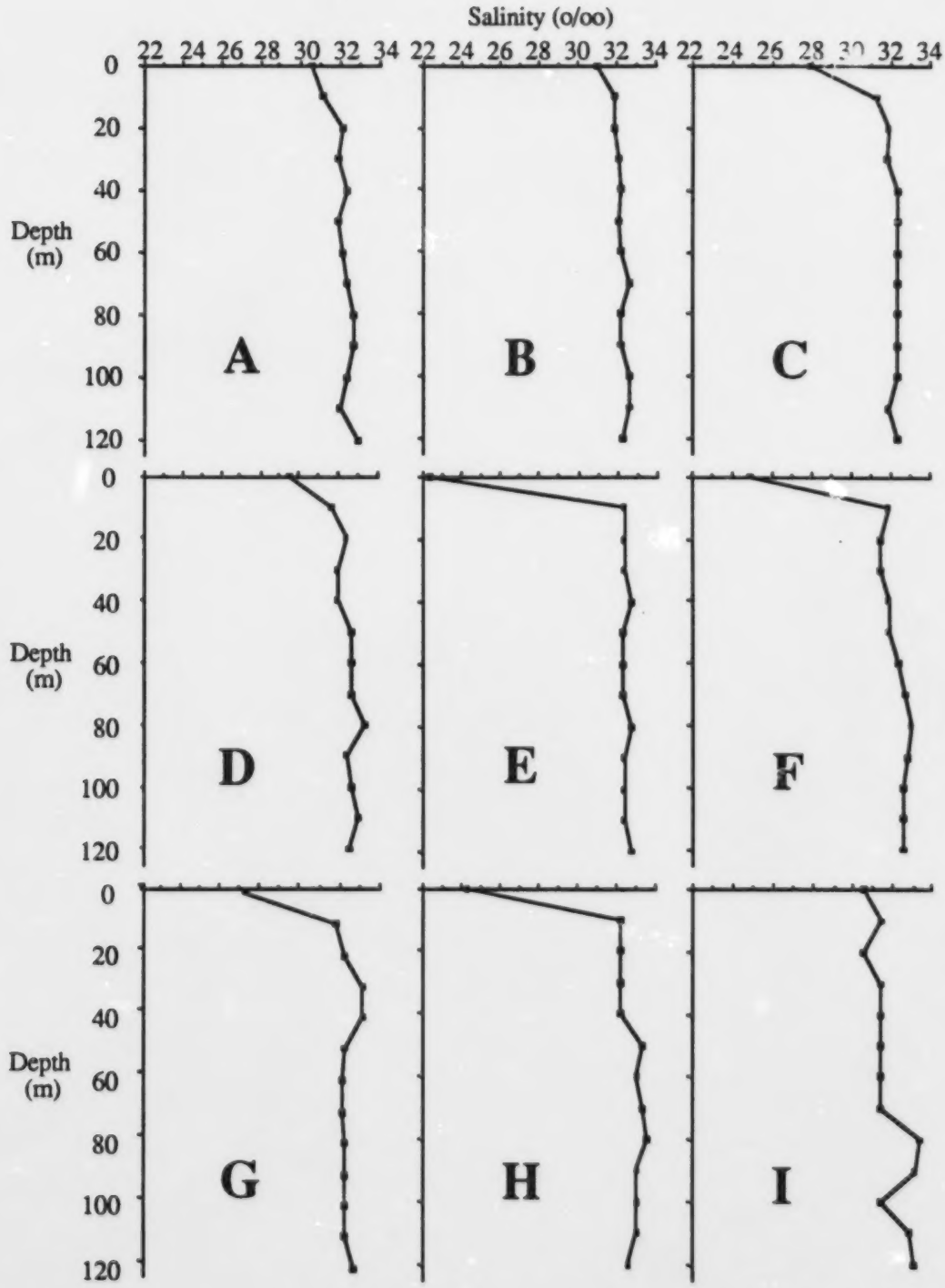

Figure 29. Salinity profiles obtained in Bonne Bay at the Pinnacle rock site in 1989: A) April 22, B) April 28, C) May 2, D) May 5, E) May 6, F) May 10, G) May 11, H) May 14, I) May 22, J) May 24, K) May 29, L) June 1, M) June 5, N) June 7, O) June 26, P) July 15, Q) July 17, R) Sept. 5.

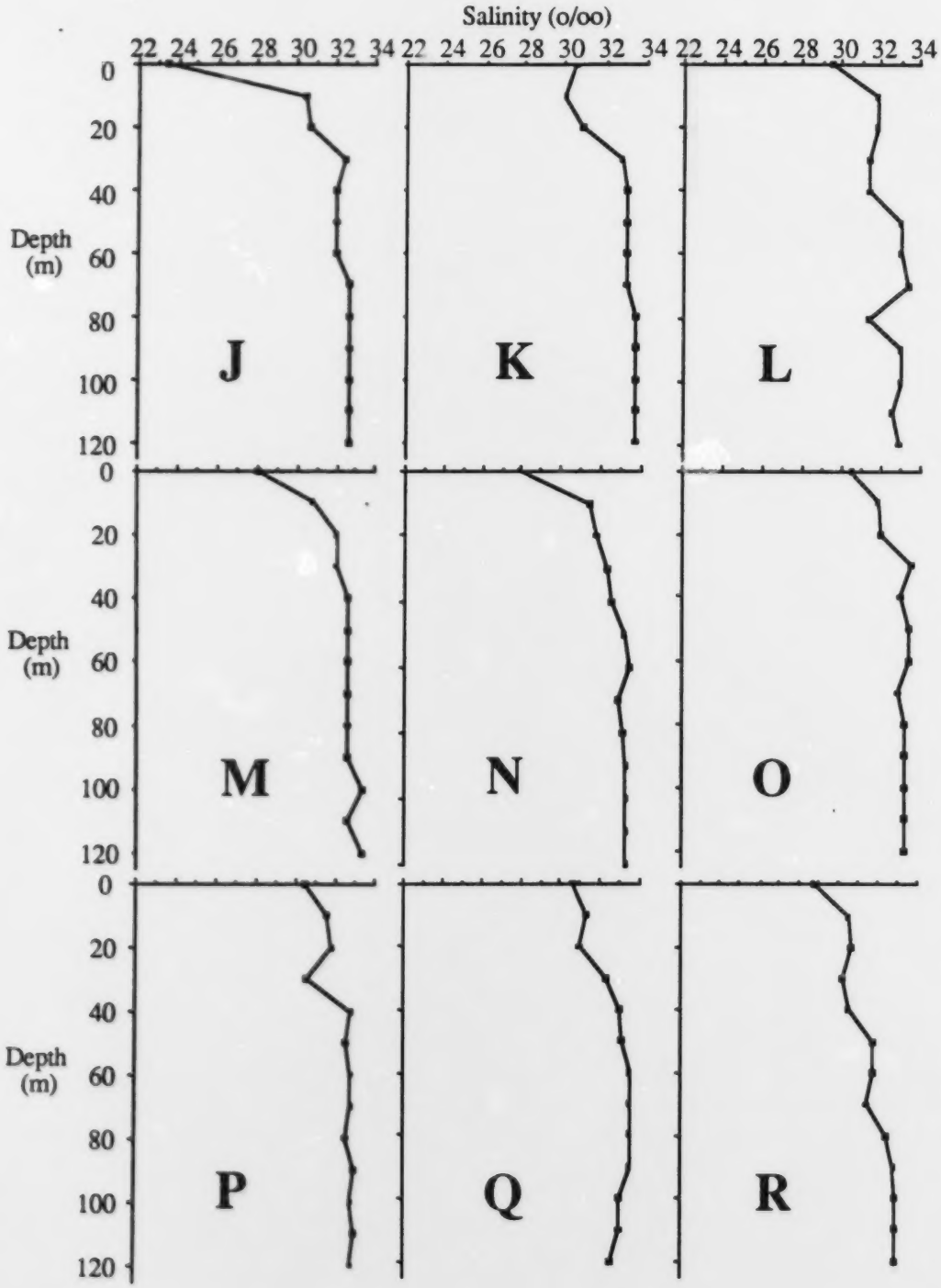

Figure 29. cont.

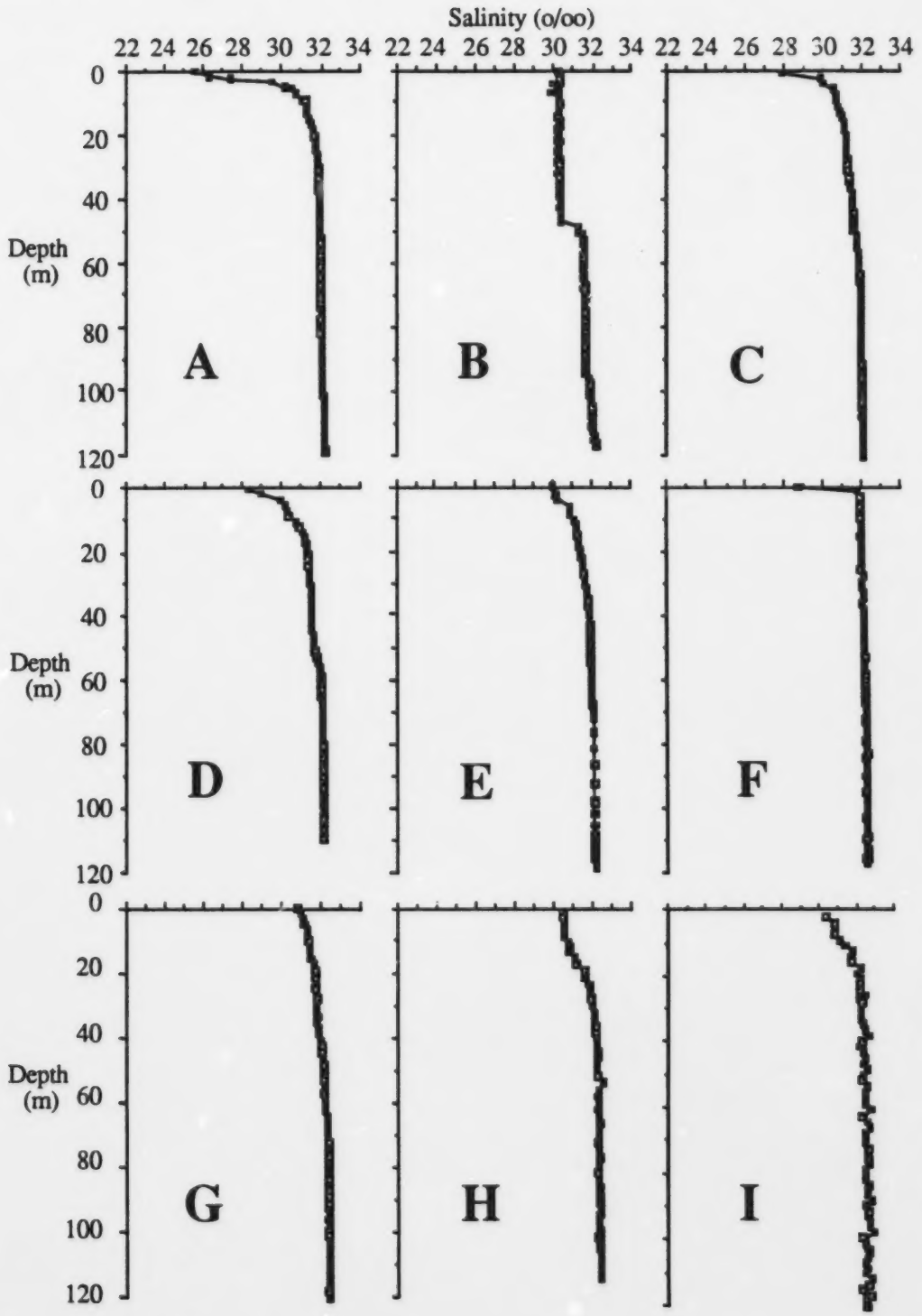

Figure 30. Salinity profiles obtained in Bonne Bay at the Pinnacle rock site in 1990: A) May 8, B) May 12, C) May 14, D) May 15, E) May 18, F) May 22, G) May 25, H) May 28, I) May 29, J) June 1, K) June 7, L) June 11, M) July 5, N) July 17, O) August 4, P) August 7, Q) August 12, R) August 22.

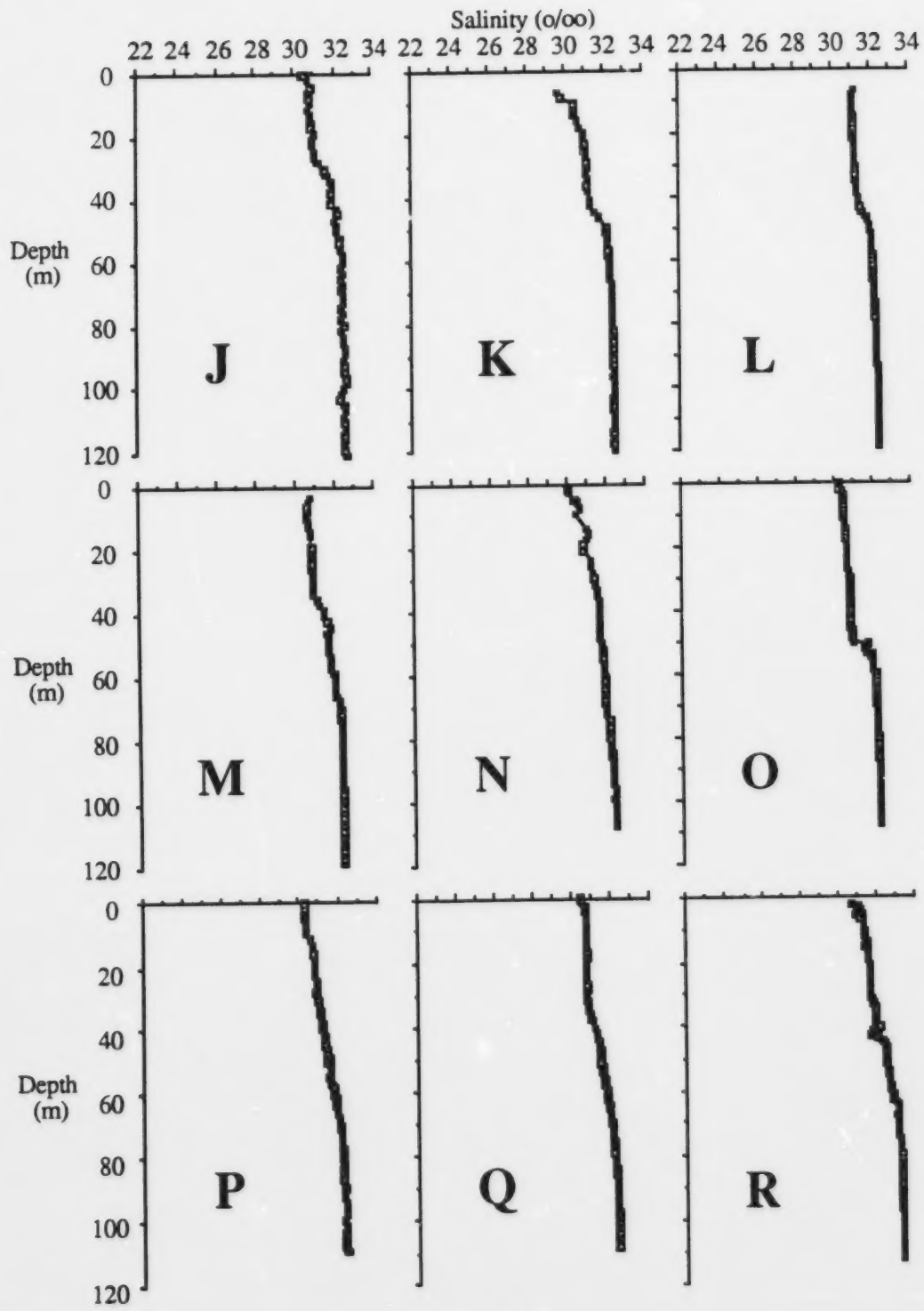

Figure 30. cont.

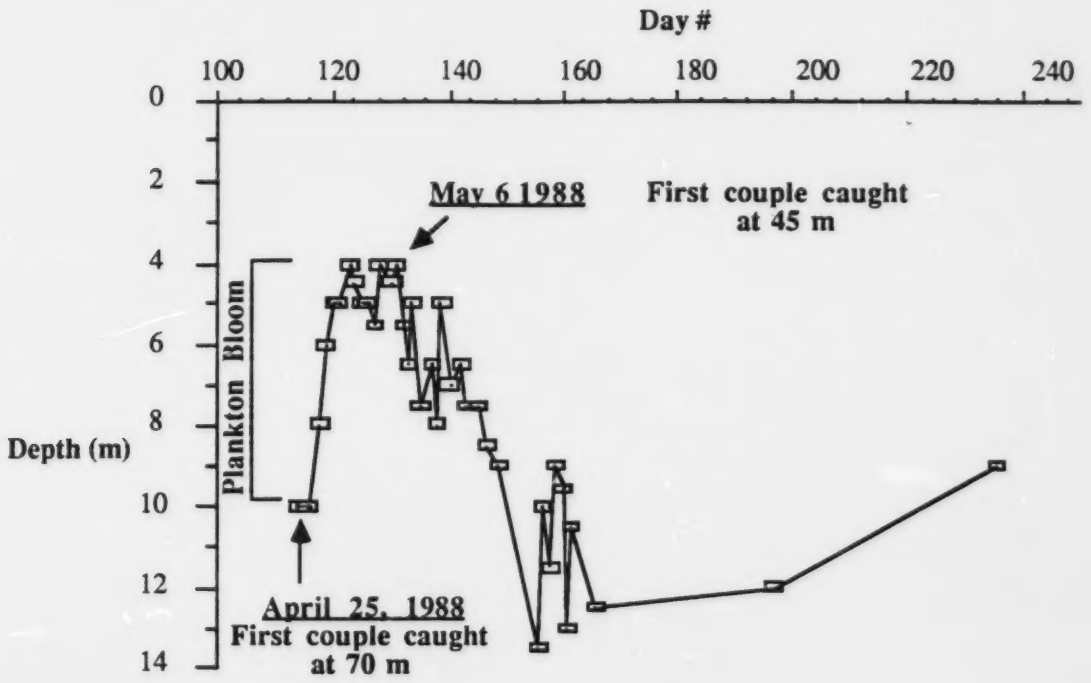

Figure 31. Secchi disk readings between April-August 1988 in Bonne Bay. A phytoplankton bloom took place on May 1. The first couples were observed on April 25 and May 6 at 70 m and 45 m respectively.

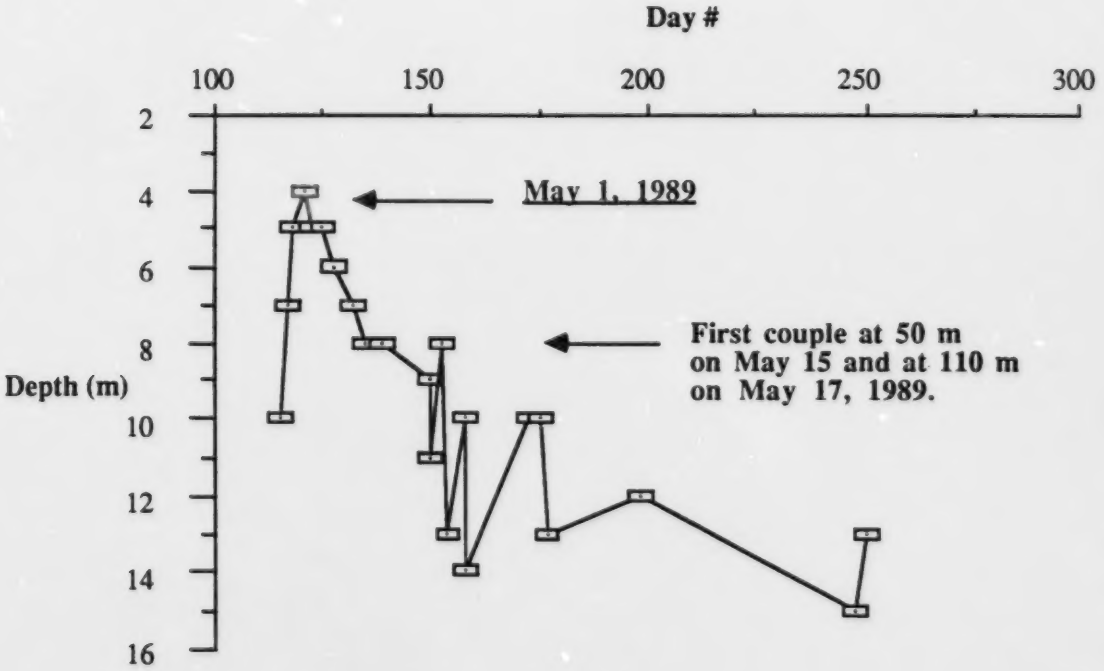

Figure 32. Secchi disk readings between April-September 1989 in Bonne Bay. A phytoplankton bloom took place on May 1. The first couples were observed on May 15 and 17 at 50 and 110 m respectively.

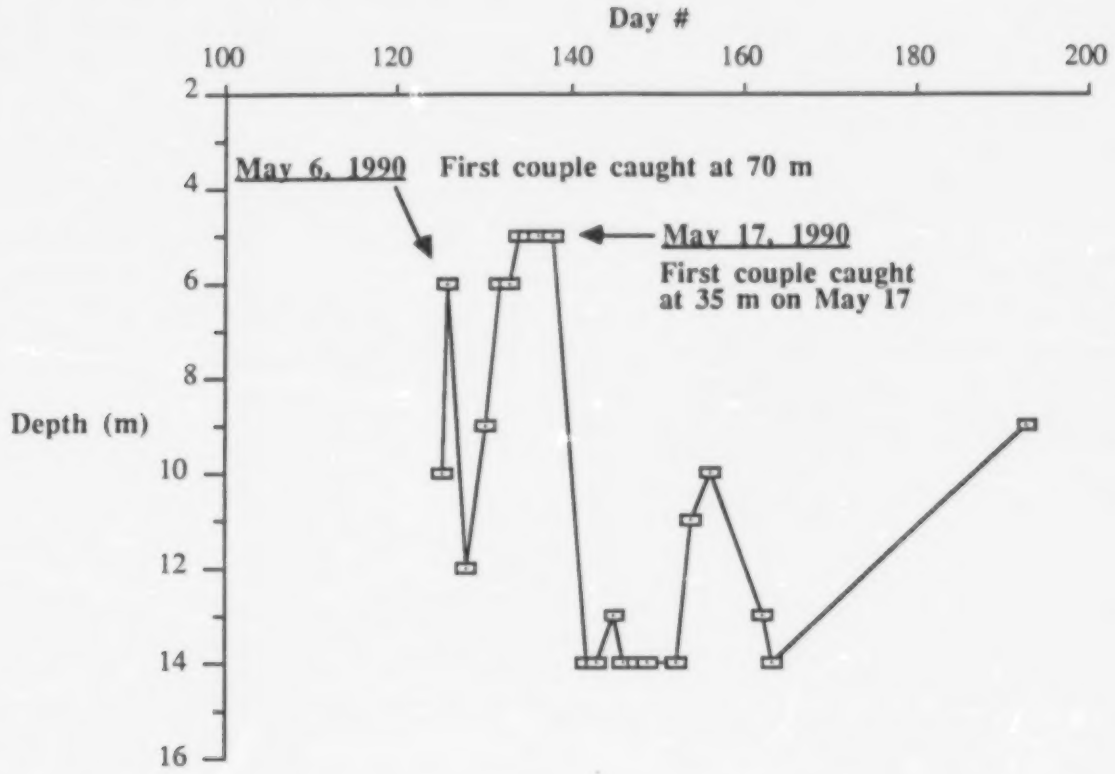

Figure 33. Secchi disk readings between May-July 1990 in Bonne Bay. A phytoplankton bloom took place on May 6. The first couples were observed on May 6 and 17 at 70 and 35 m respectively.

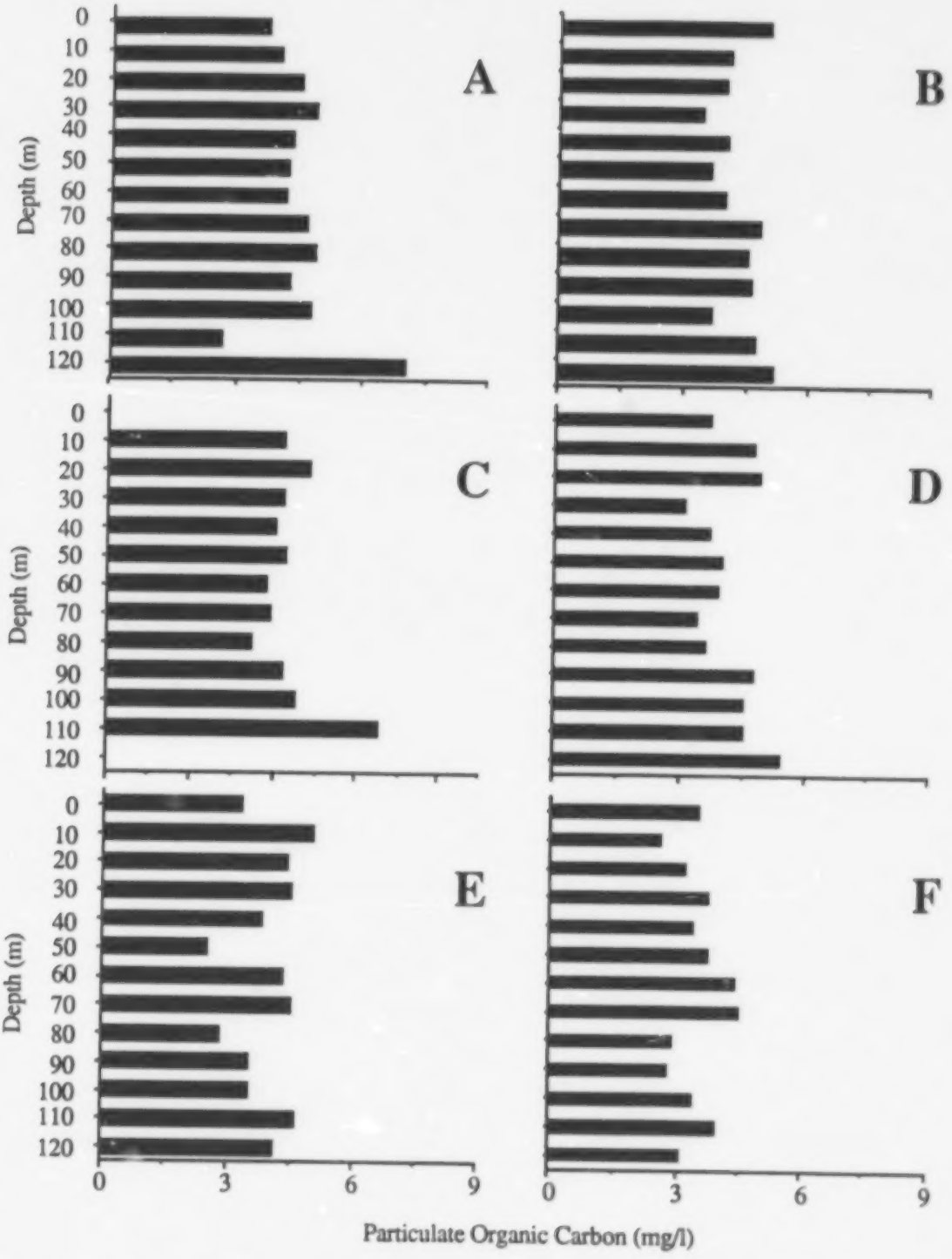

Figure 34. Bar chart showing amounts of Particulate Organic Carbon (POC) at each 10 m depth interval for samples taken in Bonne Bay - 1989: A) April 22, B) April 28, C) May 2, D) May 10, E) May 11, F) May 14, G) May 22, H) May 24, I) May 29, J) June 1, K) June 5, L) June 7, M) June 22, N) June 26, O) July 15, P) July 17, Q) Sept. 5.

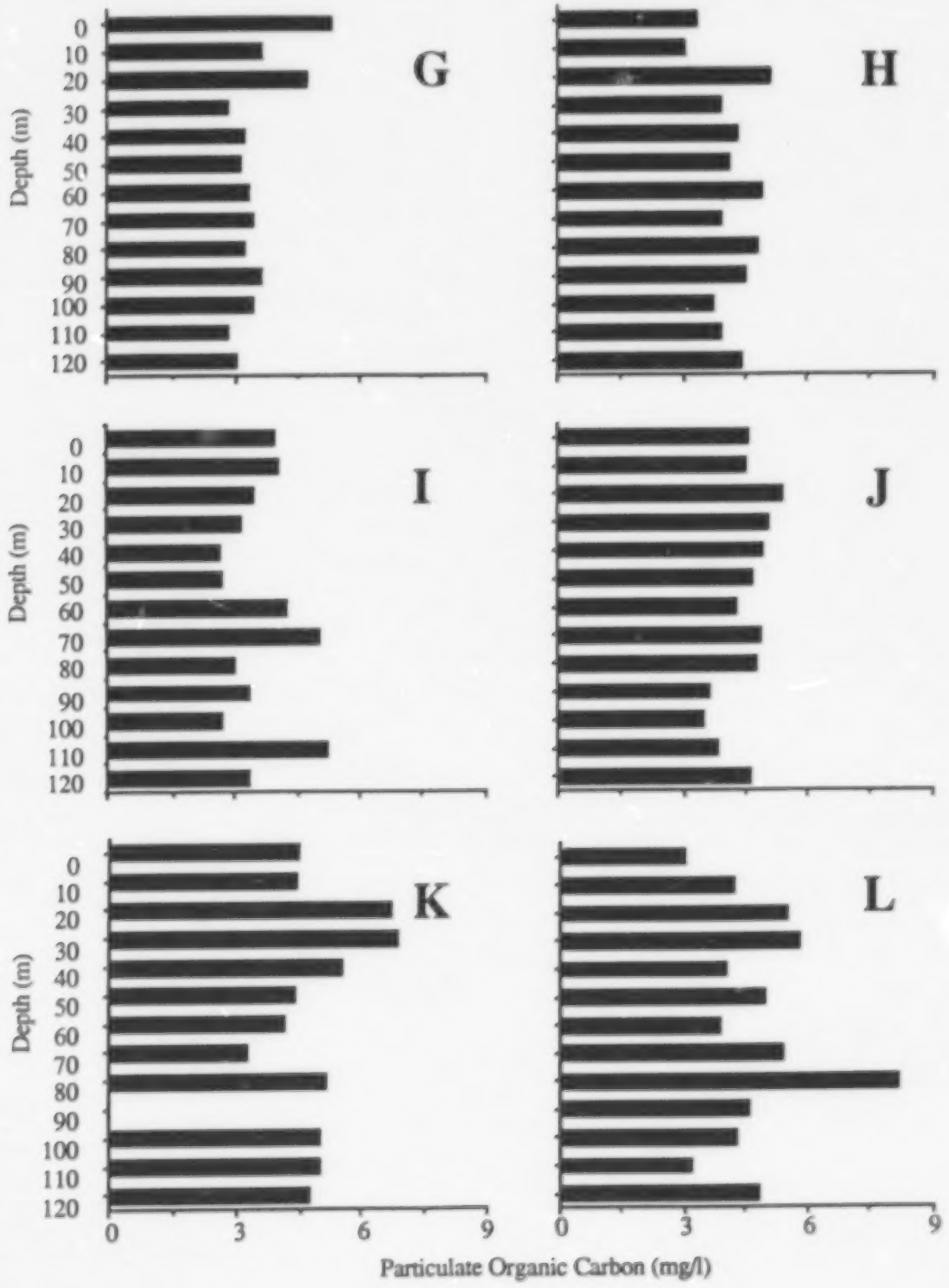

Figure 34. cont.

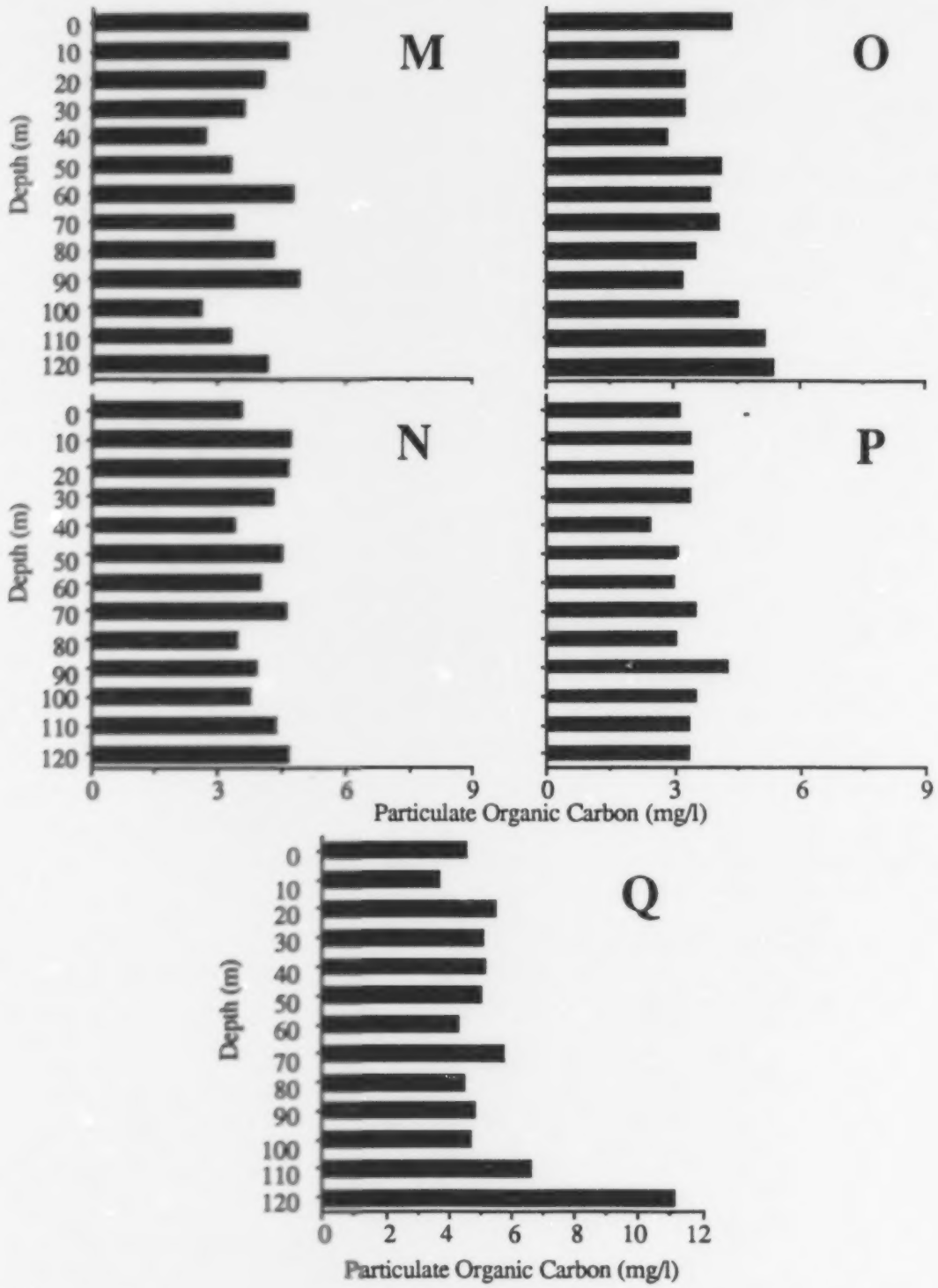

Figure 34. cont.

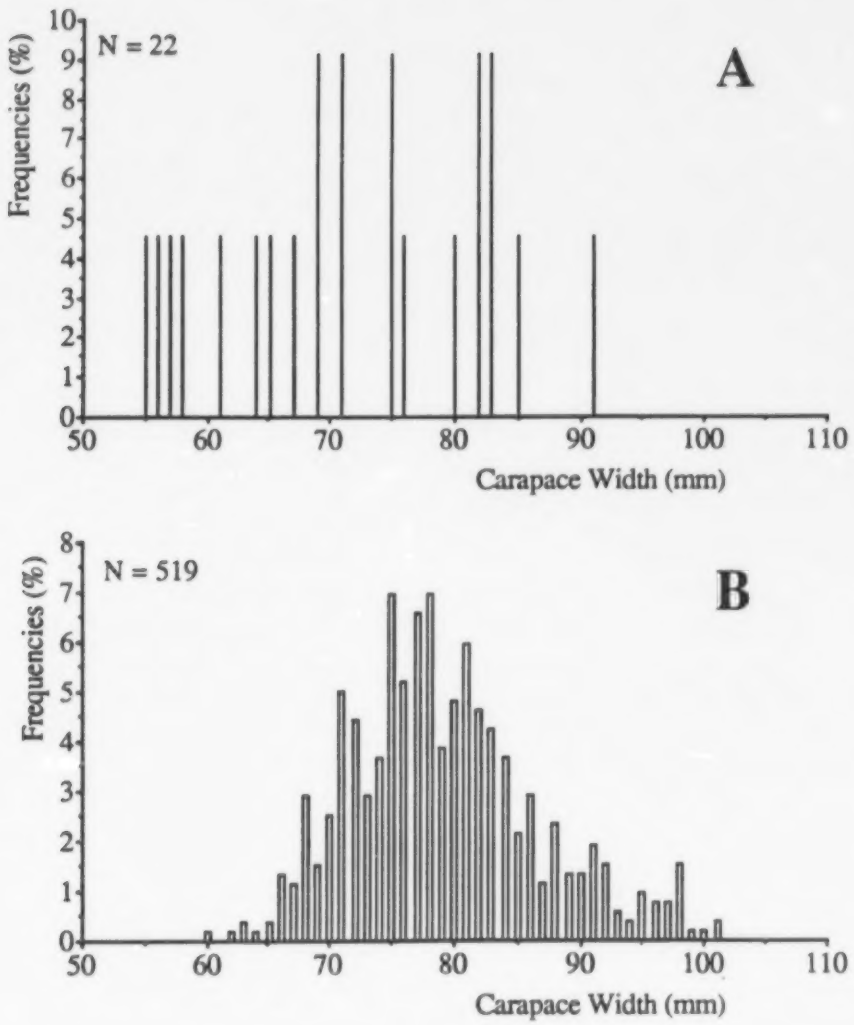

Figure 35. Size frequency distributions for male snow crab (*C. opilio*) exuviae collected by diving in Bonne Bay: A) 1989, B) 1990.

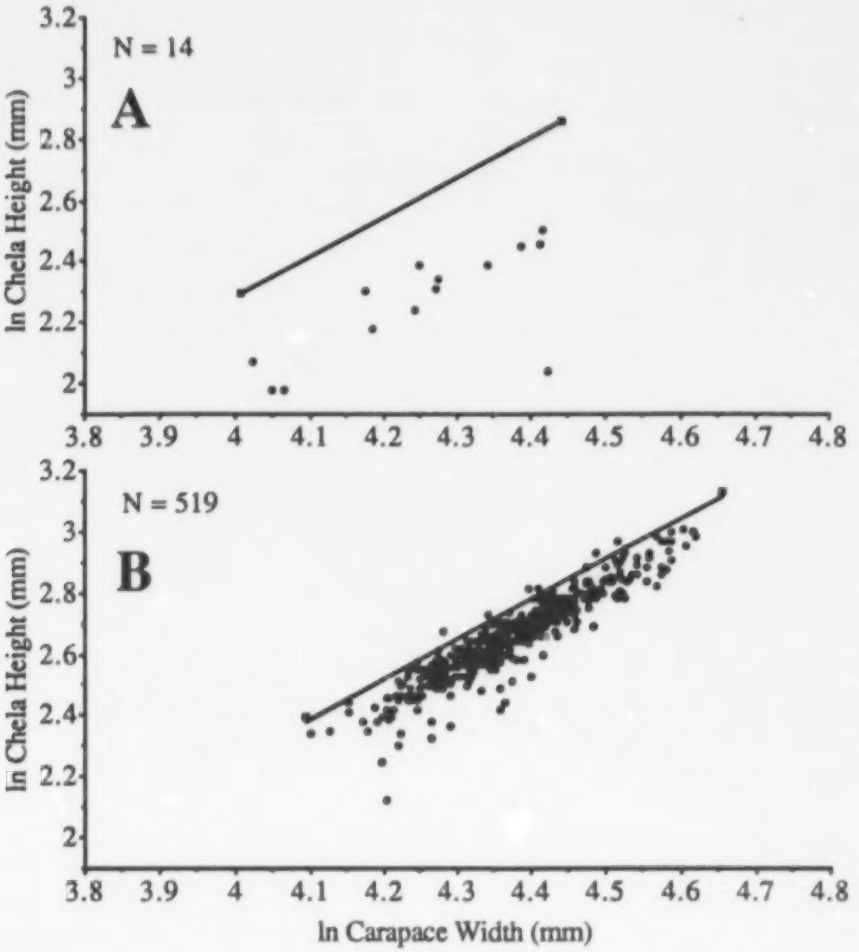

Figure 36. Chela height vs carapace width plotted on a logarithmic scale for male snow crab (*C. opilio*) exuviae collected by diving in Bonne Bay: A) 1989, B) 1990. Points below the discriminant line represent the juvenile males.

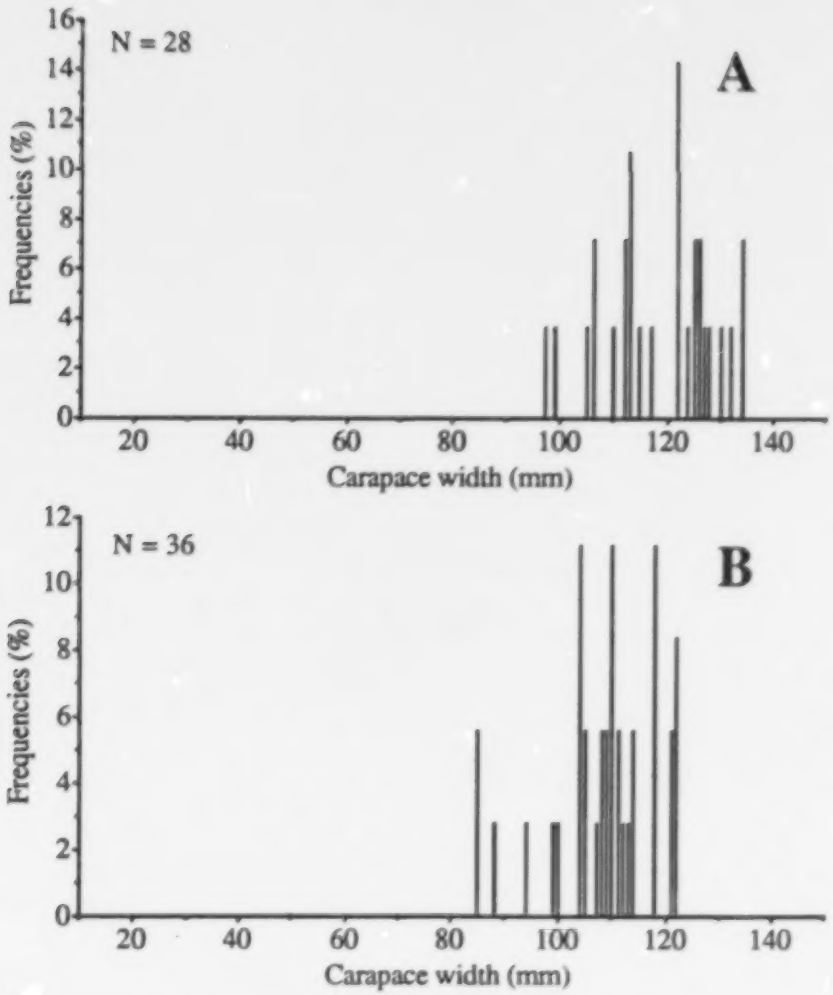

Figure 37. Size frequency distributions for male snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay: A) 1984, B) 1987. The shell condition of all male, except one in 1987, was old-shell.

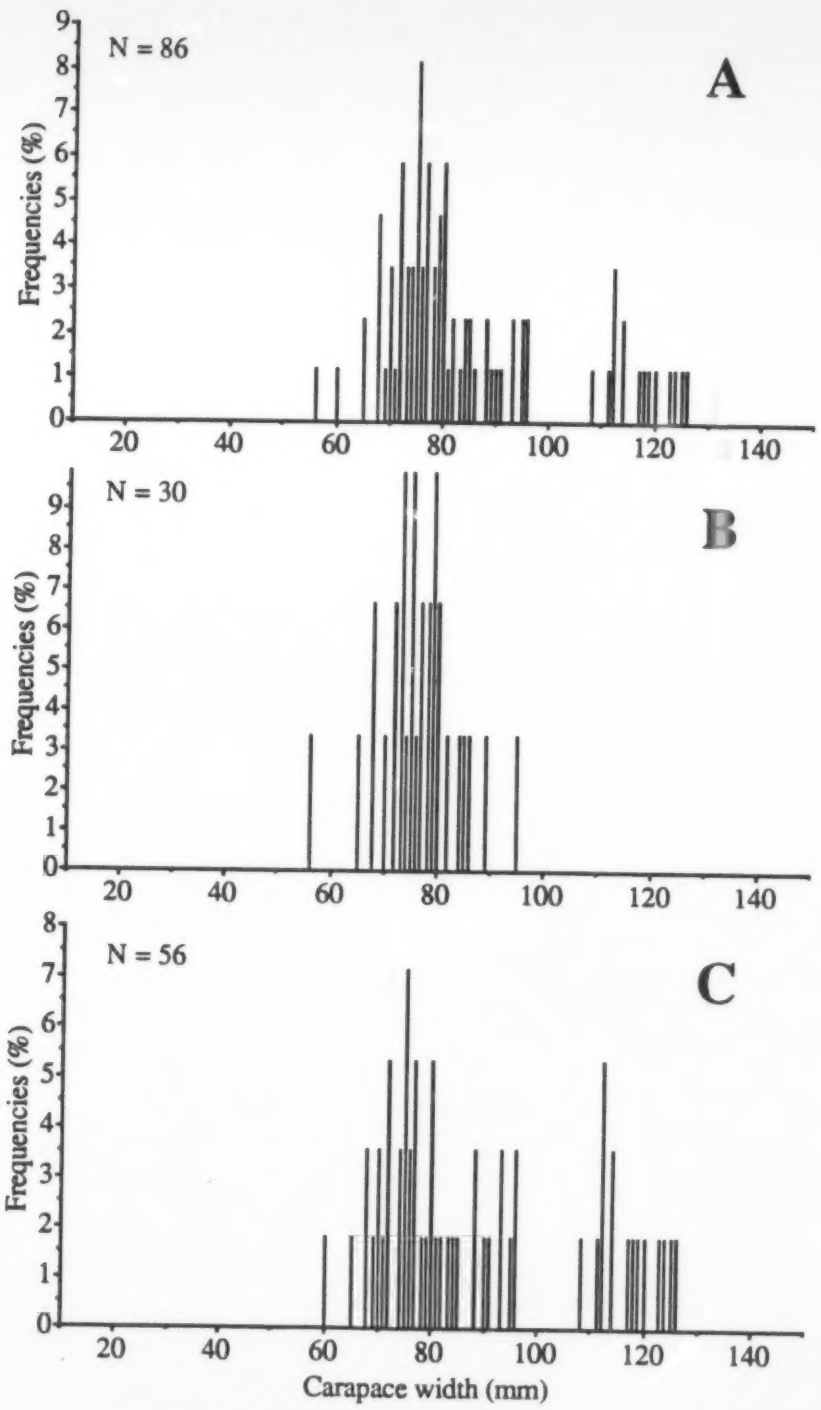

Figure 38. Size frequency distributions for male snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay - 1988: A) Total, B) New-shell, C) Old-shell.

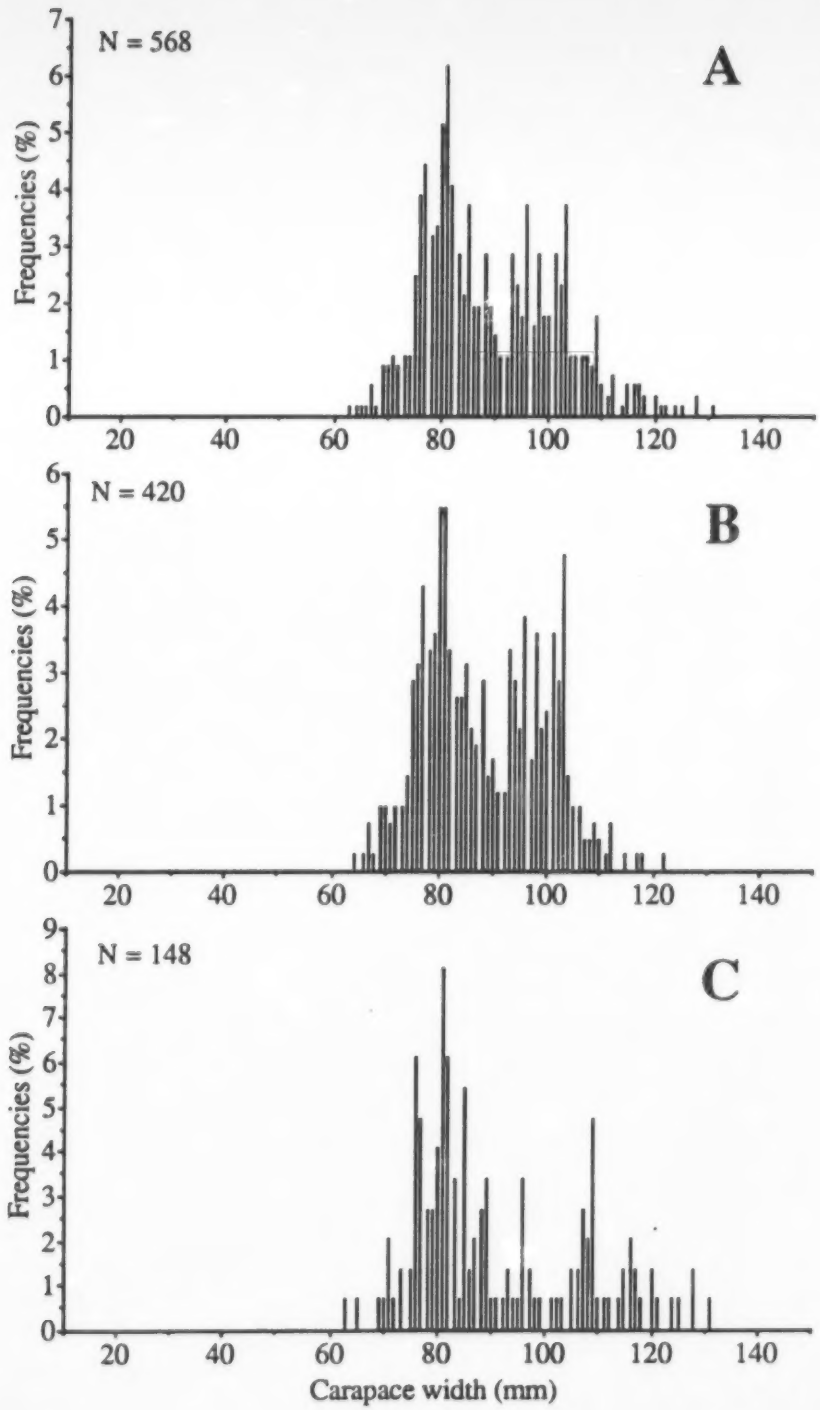

Figure 39. Size frequency distributions for male snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay - 1989: A) Total, B) New-shell. C) Old-shell.

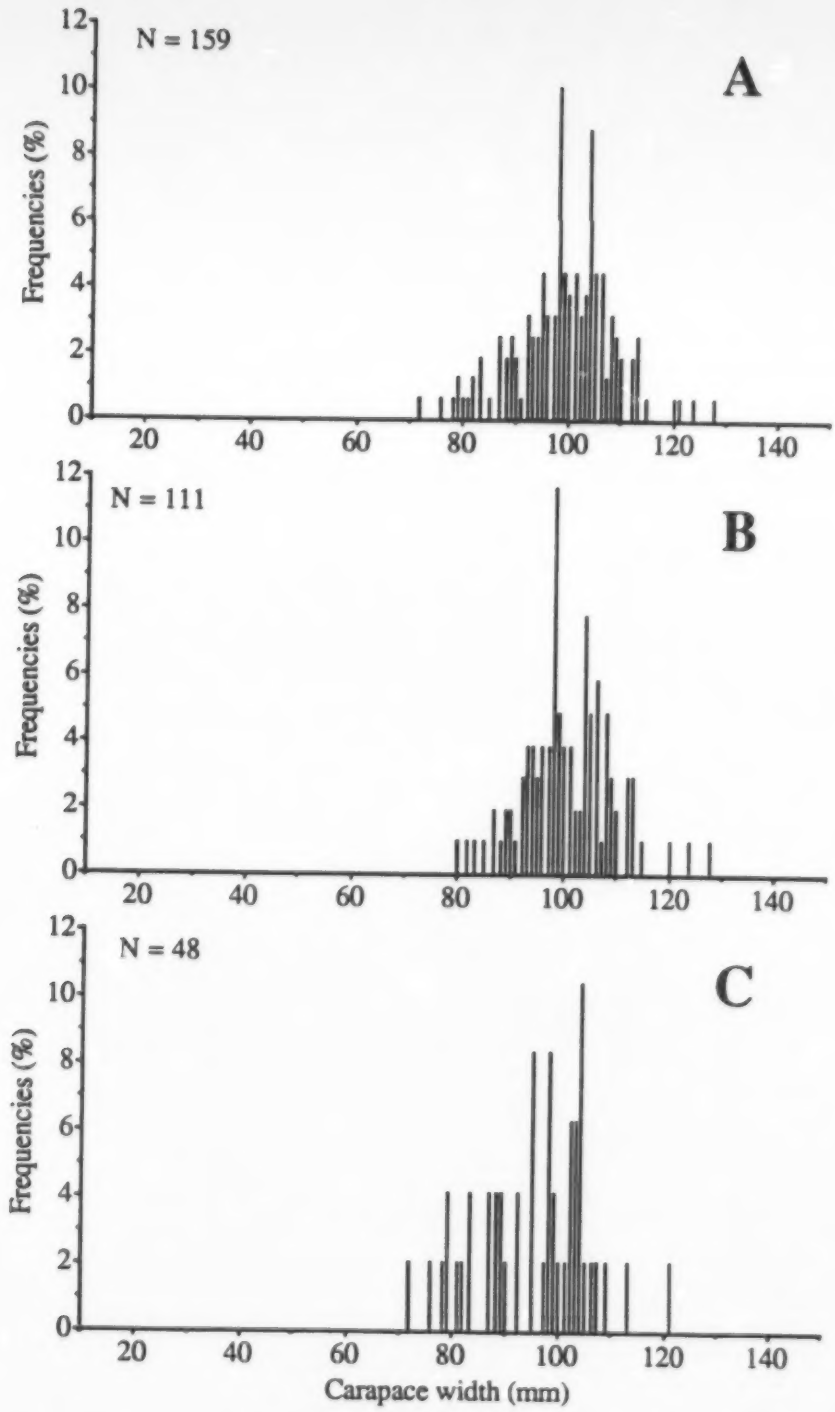

Figure 40. Size frequency distributions for male snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay - 1990: A) Total, B) New-shell, C) Old-shell.

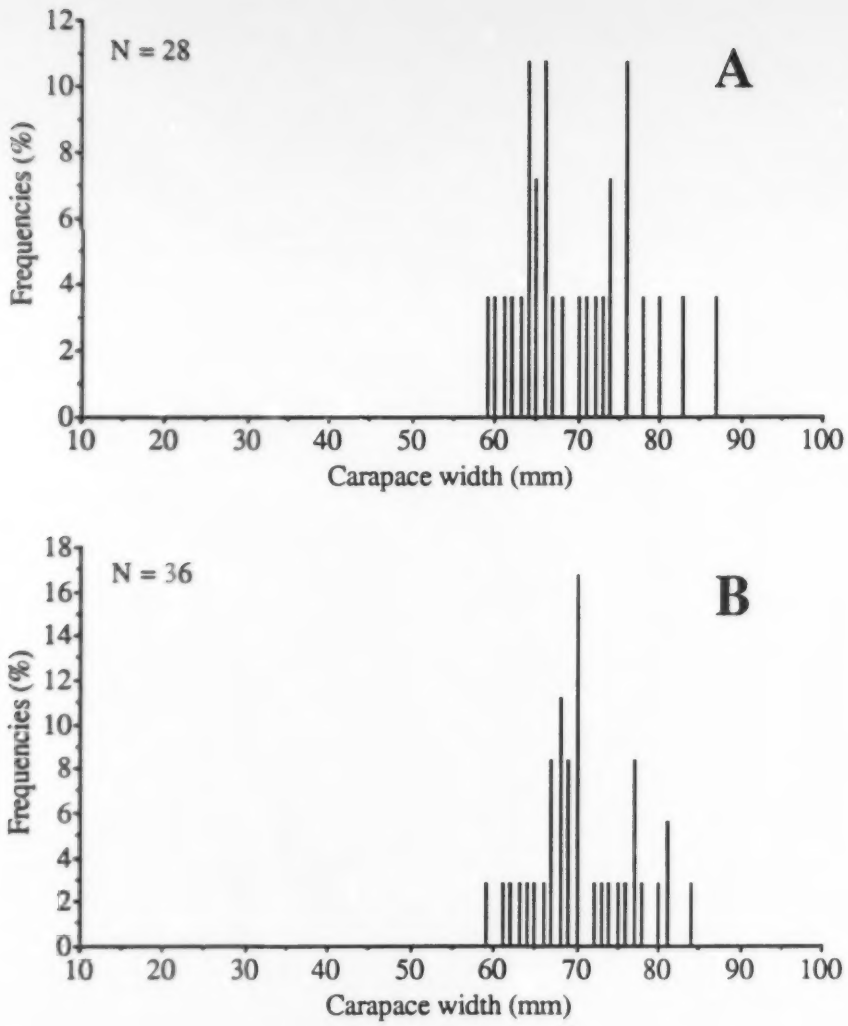

Figure 41. Size frequency distributions for female snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay: A) 1984, B) 1987. The shell condition of all females was old-shell.

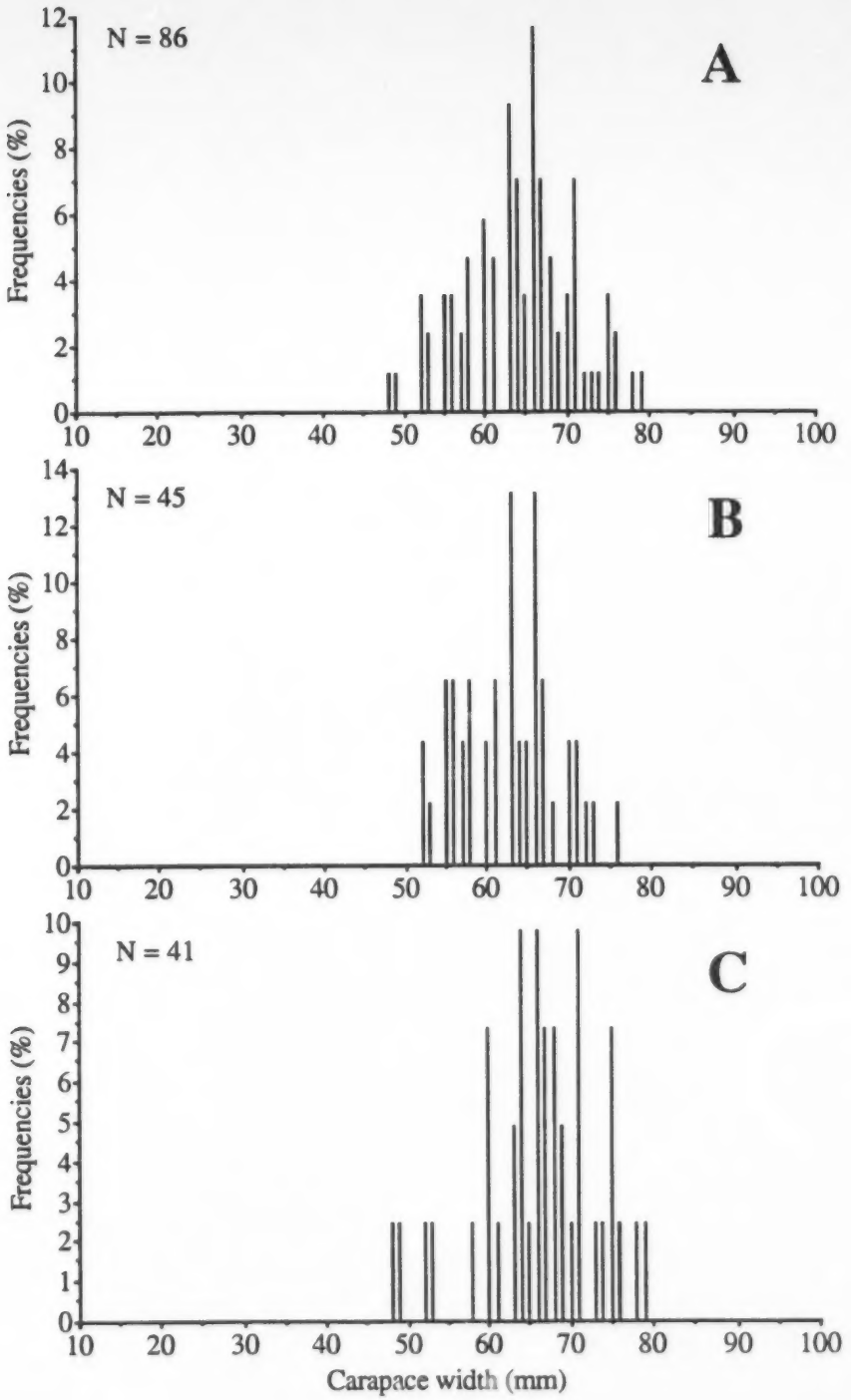

Figure 42. Size frequency distributions for female snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay - 1988: A) Total, B) New-shell, C) Old-shell.

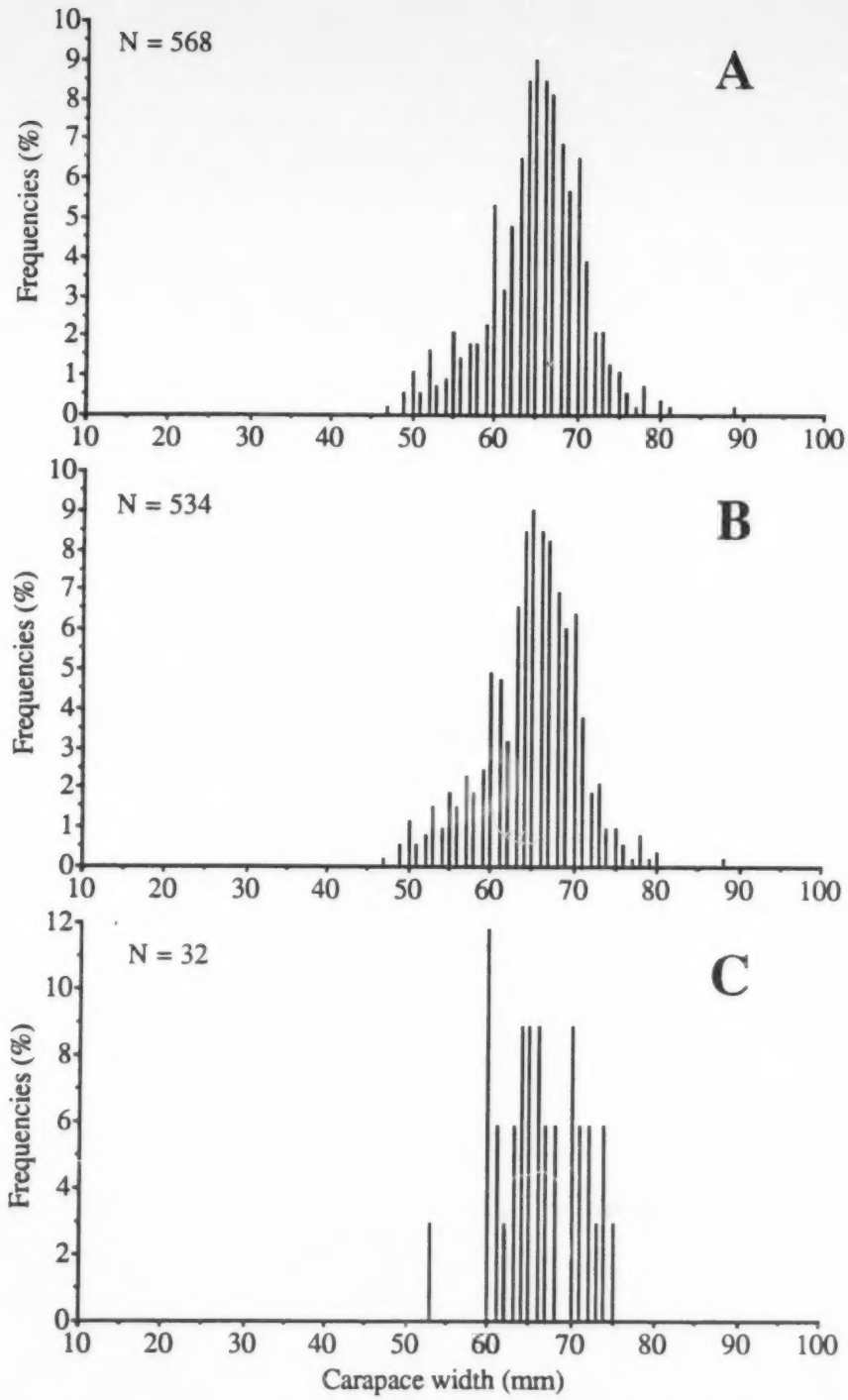

Figure 43. Size frequency distributions for female snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay - 1989: A) Total, B) New-shell, C) Old-shell.

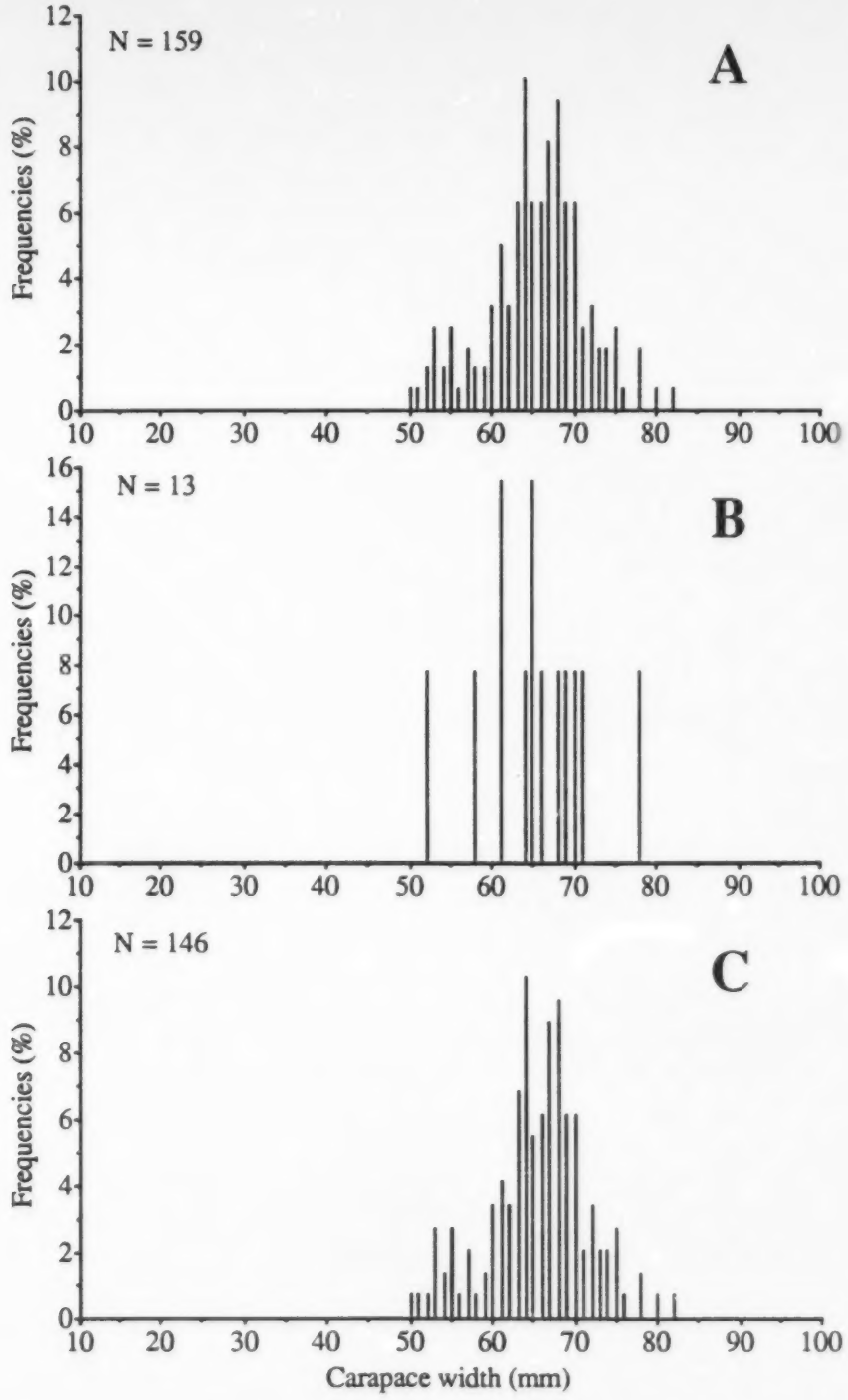

Figure 44. Size frequency distributions for female snow crab (*C. opilio*) caught during the pre-copulatory embrace in Bonne Bay - 1990: A) Total, B) New-shell, C) Old-shell.

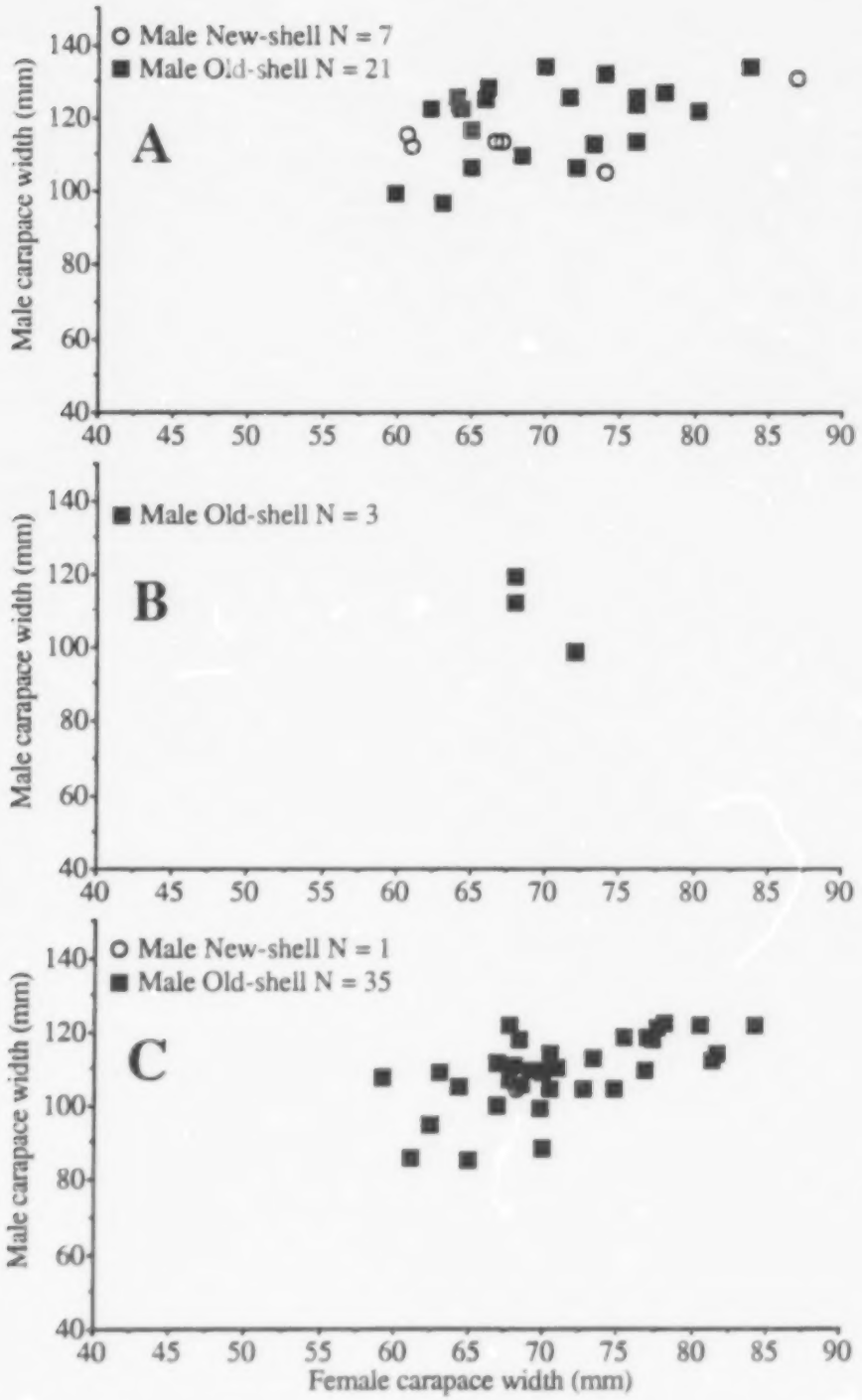

Figure 45. Couple ratios for all sexually paired snow crab (*C. opilio*) collected in Bonne Bay: A) 1984, B) 1985, C) 1987, D) 1988, E) 1989, F) 1990.

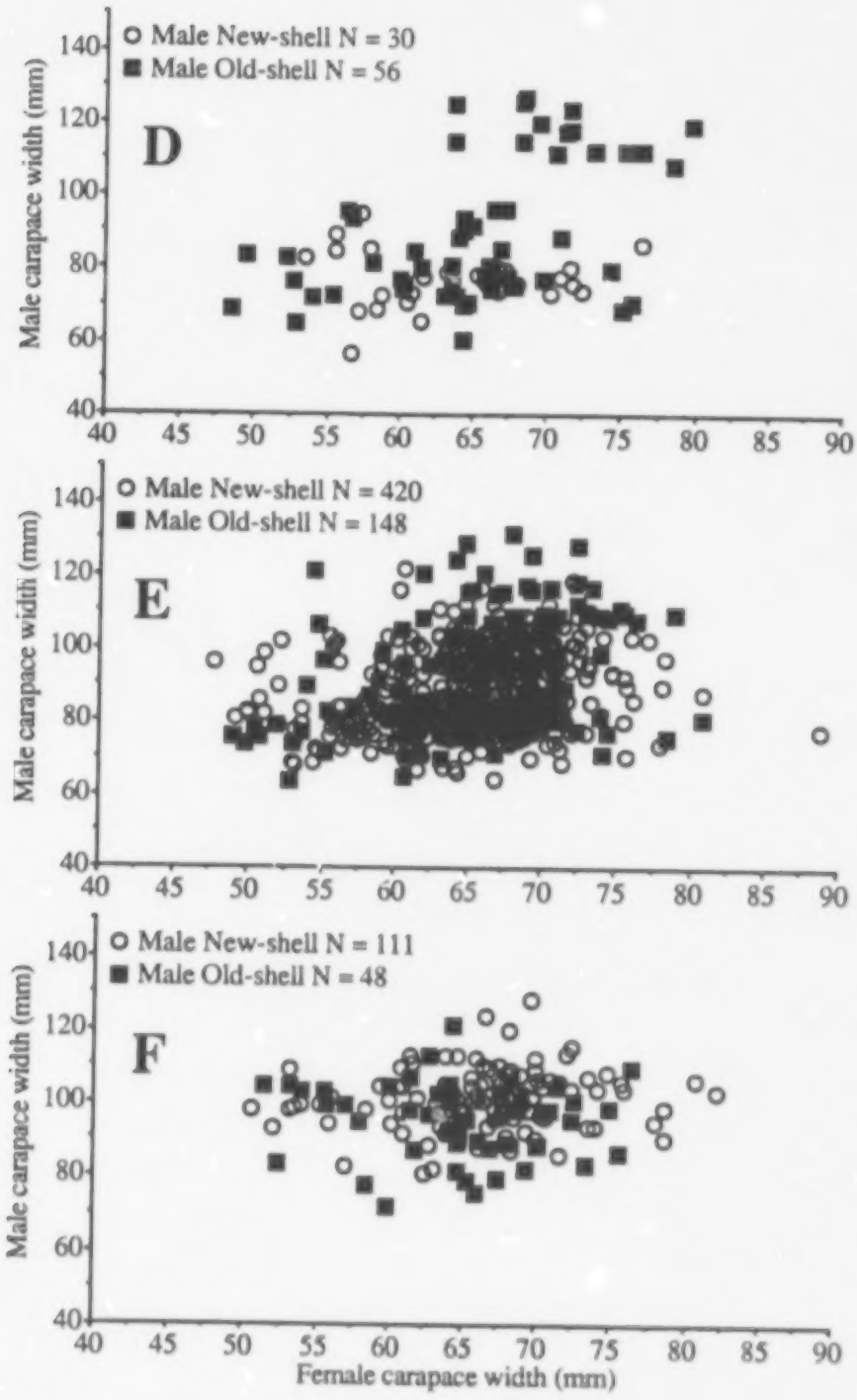

Figure 45. cont.

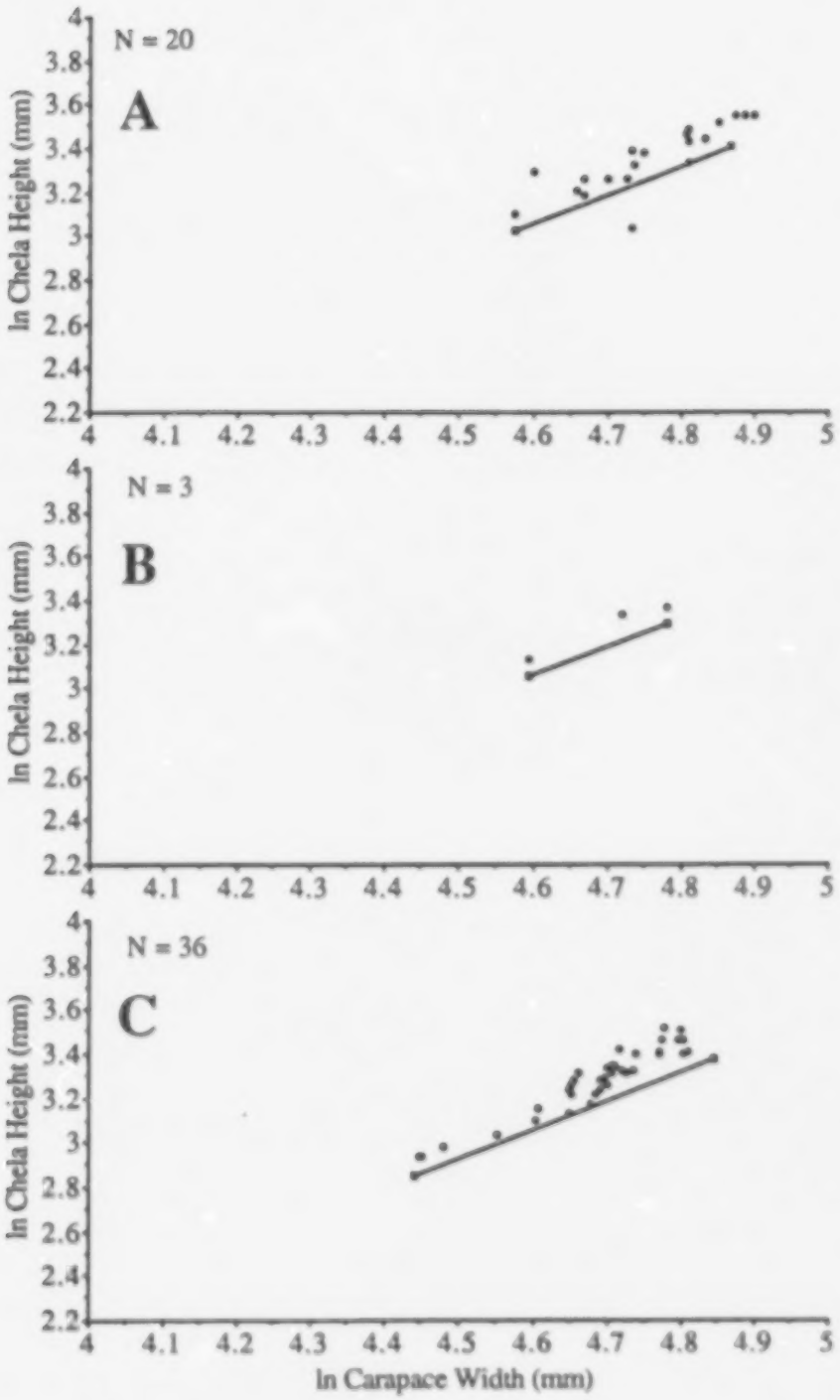

Figure 46. Chela height vs carapace width plotted on a logarithmic scale for sexually paired male snow crab (*C. opilio*) caught by diving and tangle net in Bonne Bay: A) 1984, B) 1985, C) 1987, D) 1988, E) 1989 and F) 1990. Points above the discriminant line represent the morphometrically mature males.

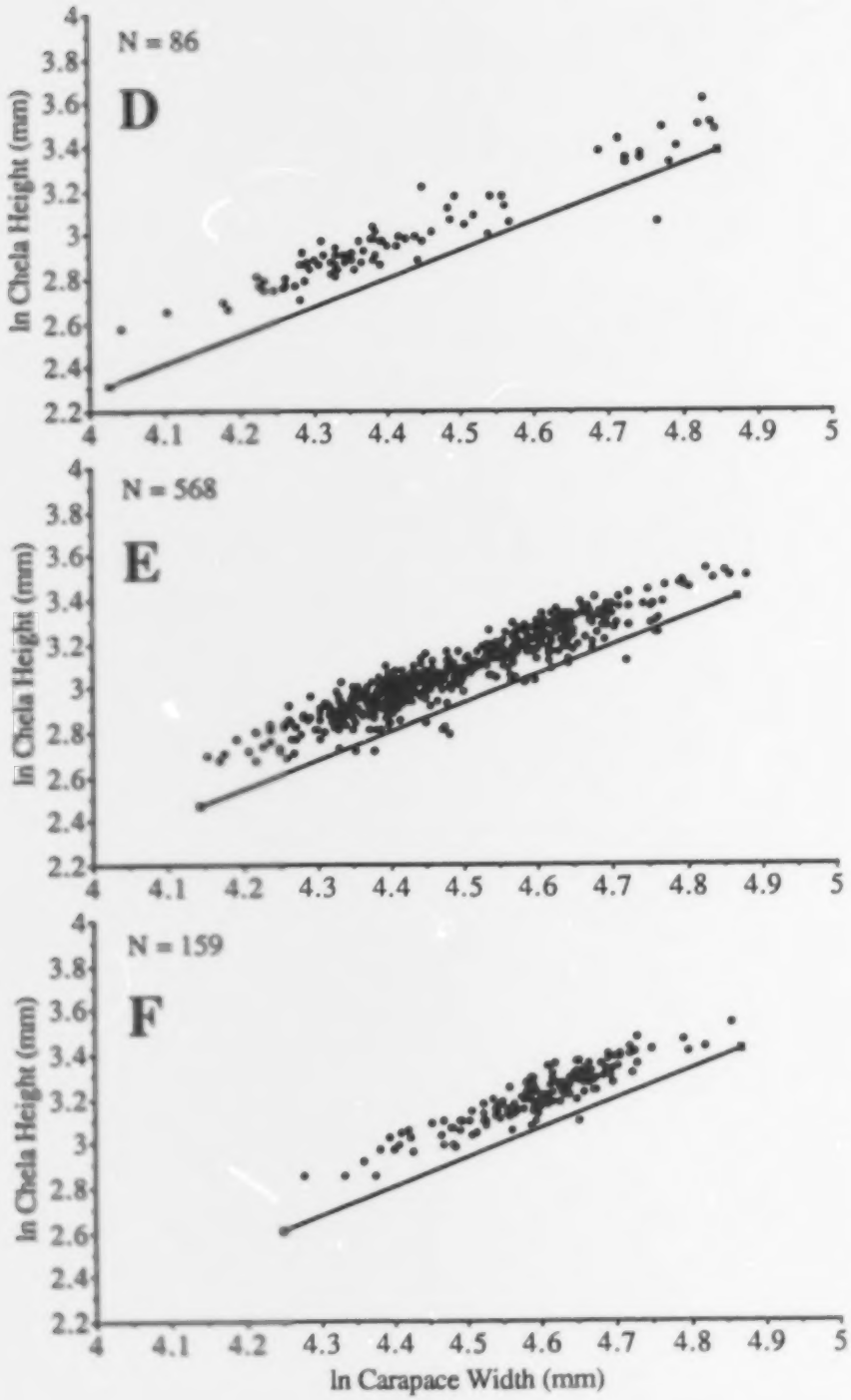

Figure 46. cont.